# REPRINTS OF PAPERS

FROM

# THE SCIENCE LABORATORIES

OF

# THE UNIVERSITY OF SYDNEY

1909-10 TO 1915-16

# B

VOL. II.

FROM THE DEPARTMENTS OF GEOLOGY
PATHOLOGY AND PHYSIOLOGY

FOR PRIVATE CIRCULATION ONLY



SYDNEY, 1916

## NOTE

A NUMBER of the papers issued from the Laboratories of the Departments of Geology, Pathology and Physiology during the period 1909-10 to 1915-16 were not available for inclusion in this volume. The following list comprises these as well as the actual contents of the volume, the latter being distinguished by asterisks.

## GEOLOGY

### William Noel Benson, D.Sc., B.A. (Cantab.), F.G.S.

*Student Demonstrator in Geology*, 1907. *Junior Demonstrator in Geology*, 1909-10. *Science Scholar of the Royal Commissioners for the Exhibition of* 1851, 1911. *Linnean Macleay Fellow in Geology*, 1914-1915. *Acting Lecturer in Geology*, 1916—

1. The volcanic necks of Hornsby and Dundas, near Sydney. *Jour. and Proc. Roy. Soc. N.S.W.* for 1910, 26 July 1911, xliv, pt. 4, pp. 495-555, plate XXXIV, 14 text-figs.
2. Note descriptive of a stereogram of the Mount Lofty ranges, South Australia. *Trans. Roy. Soc. S. Aus.* for 1911, xxxv, pp. 108-111, plates XX-XXI.
. Preliminary note on the nepheline bearing rocks of the Liverpool and Mt. Royal Ranges. *Jour. and Proc. Roy. Soc. N.S.W.*, Feb. 8 1912, xlv, pt. ii, pp. 174-186, plates VI.-VII, 3 text-figs.
3. Spilite lavas and radiolarian rocks in New South Wales. *Geol. Mag.*, 13 Jan. 1913, x (Decade v), no. 583, pp. 17-21. [Work done as 1851 Science Research Scholar.]
. The Scamander mineral district *Geological Survey of Tasmania Bulletin*, No. 9, 1911, p. 16-17.
. Model for a polarising microscope. *Geol. Mag.*, Oct. 1913 Dec. v, no. 592, pp. 447-8, 1 text-fig.
. A preliminary account of the geology of Nundle district near Tamworth, N.S.W. *Rept. Aust. Ass. Adv. Science*, 1911, pp. 100-106, plate II and 1 figure.
4. The geology and petrology of the great serpentine belt of New South Wales, parts I, II, III. *Proc. Linn. Soc. N.S.W.*, 19 Dec. 1913, xxxviii, pt. 3 (no. 151), pp. 491-517, plates XX-XXI; 23 March 1914, xxxviii, pt. 4 (no. 152), pp. 569-596, plates XXII-XXIV; 23 March 1914, xxxviii, pt. 4 (no. 152), pp. 662-724, plates XXVII-XXIX. [Work done as 1851 Science Research Scholar.]
*5. Petrological notes on various New South Wales rocks. *Proc. Linn. Soc. N.S.W.*, 25 Sept. and 24 Nov. 1914, xxxix, pts. 2 and 3 (nos. 154-155), pp. 447-453.
*6. The geology and petrology of the great serpentine belt of New South Wales. Part IV. The dolerites, spilites and keratophyres of the Nundle district. *Proc. Linn. Soc. N.S.W.*, 16 June 1915, xl, pt. 1, (no. 157), pp. 121-173, plates XXV-XXVII, 6 text-figs. Part V. The geology of the Tamworth district. *Proc. Linn. Soc. N.S.W.*, 10 Dec. 1915, xl, pt 3 (no. 159), pp. 540-624, plates XLIX-LIII.
*7. Notes on the geology of the Cradle Mountain district; with a bibliography of the pleistocene glaciation of Tasmania. Reprint *Proc. Roy. Soc. of Tasmania*, 1916, pp. 1-15, plates I-IV.

### William Rowan Browne, B.Sc.

*Junior Demonstrator in Geology*, 1911-1912. *Assistant Lecturer and Demonstrator in Geology*, 1913—

1. The geology of the eruptive and associated rocks of Pokolbin, N.S. Wales. *Jour. and Proc. Roy. Soc. N.S.W.*, 26 June 1912, xlv, pt. 3, pp. 379-408, plates XXV-XXVIII. [With A. B. Walkom.]
2. The geology of the Cooma district, N.S.W. Part I. *Jour. and Proc. Roy. Soc. N.S.W.*, 1914, 25 Nov. 1914, xlviii, pt. 2, pp. 172-222, plates II-V.

### Leo Arthur Cotton, B.A., B.Sc.

*Assistant Lecturer and Demonstrator in Geology*, 1911— *Evening Lecturer in Geology* 1915—

1. Note on the limitations of De Chaulnes' method of determining refractive index. *Rept. Aus. Ass. Adv. Sci.* 1911, 23 April 1912, xiii, pp. 120-124, 2 text-figs.
2. Some crystal measurements of chillagite. *Jour. and Proc. Roy. Soc. N.S.W.*, 25 March 1913, xlvi, pt. 2, pp. 207-219, plates XV, XVI. [With C. D. Smith.]
*3. Note on the relation of the devonian and carboniferous formations west of Tamworth, N.S.W. *Proc. Linn. Soc. N.S.W.*, 22 July 1913, xxxvii, pt. 4 (no. 148), pp. 703-708. [With A. B. Walkom.]
*4. The diamond deposits of Copeton, New South Wales. *Proc. Linn. Soc. N.S.W.*, 26 Feb. 1915, xxxix, pt. 4 (no. 156), pp. 803-838, plates XC-XCII.
*5. Some geo-physical observations at Burrinjuck, N.S.W. *Jour. and Proc. Roy. Soc. N.S.W.* 1915, 28 April 1916, xlix, pt. 3, pp. 448-462, plate LXII, 3 text-figs.

### T. W. Edgeworth David, C.M.G., B.A., D.Sc., F.R.S. (New College, Oxford).

*Professor and William Hilton Hovell Lecturer in Geology*, 1891—

1. Geological notes of the British Antarctic Expedition 1907-09. Extrait du *Compte Rendu du XI:e Congrès Géologique International*, 1912, pp. 767-811. [With R. E. Priestley.]

2. British Antarctic Expedition 1907-9 under the command of Sir E. H. Shackleton, C.V.O. Reports on the scientific investigations. Geology. Vol. I. Glaciology, physiography, stratigraphy, and tectonic geology of South Victoria Land; with short notes on palæontology by T. G. Taylor and E. J. Goddard. London, William Heinemann, 1914, 4to. Pp. xxiv, 319, 1 blank, 96 plates, 67 text-figs. [With R. E. Priestley.]
*3. Presidential address to Australasian Association for the Advancement of Science. *Rept. Aus. Assoc. Adv. Sci.* Melbourne 1913, 1914, xiv, pp. xliii-xcii.
4. A preliminary communication on an Australian cranium of probable pleistocene age. *Med. Jour. of Aus.*, 26 Sept. 1914, i, no. 13, p. 308. [With J. T. Wilson.]
*5. Discovery by the Australasian Antarctic Expedition of important submarine banks. *Geog. Jour.*, May 1913, xli, no. 5, pp. 461-463, 2 figs.
6. Mawson's Australasian Antarctic expedition. *Nature*, 21 Aug. 1913, xci, p. 651.
7. Antarctic problems: paper read before the Royal Geographical Society. *Nature*, 19 Feb. 1914, xcii, pp. 700-702.
8. Note on an expedition to Dutch New Guinea: paper delivered by A. F. R. Wollaston before the Royal Geographical Society, London. *Geogr. Jour.*, March 1914, xliii, no. 3, pp. 272-273.
9. Antarctica and some of its problems. *Geogr. Jour.*, June 1914, xliii, no. 6, pp. 605-630, 8 figs.
10. Remarks on physiography and glacial geology of east Antarctica: paper read before the Royal Geographical Society, London. *Geogr. Jour.*, Dec. 1914, xliv, no. 6, pp. 566-568.
11. On the term permo-carboniferous and on the correlation of that system. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, pp. 379-380. [With W. S. Dun.]
12. Preliminary communication on an Australian cranium of probable pleistocene age. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 531. [With J. T. Wilson.]

### Catherine Drummond Smith, B.Sc.

*Junior Demonstrator in Geology*, 1911

*1. Some crystal measurements of chillagite. *Jour. and Proc. Roy. Soc. N.S.W.*, 25 March, 1913, xlvi, pt. 2, pp. 207-219, plates xv, xvi. [With L. A. Cotton.]

### Arthur Bache Walkom, B.Sc.

*Junior Demonstrator in Geology and Physical Geography*, 1910-11. *Linnean Macleay Fellow in Geology*, 1912-13.

1. Note on a new species of Favosites from Yass district, N.S.W. *Proc. Linn. Soc. N.S.W.*, 16 May 1912, xxxvi, pt. 4 (no. 144), pp. 700-701, plates xxx-xxxi.
2. The geology of the eruptive and associated rocks of Pokolbin, N.S. Wales. *Jour. and Proc. Roy. Soc. N.S.W.* 1911, 26 June 1912, xlv, pt. 3, pp. 379-408, plates xxv-xxviii. [With W. R. Browne.]
3. Note on the relation of the devonian and carboniferous formations west of Tamworth, N.S.W. *Proc. Linn. Soc. N.S.W.*, 22 July 1913, xxxvii, pt. 4 (no. 148), pp 703-708. [With L. A. Cotton.]
*4. Stratigraphical geology of the permo-carboniferous system in the Maitland-Branxton district. *Proc. Linn. Soc. N.S.W.*, 17 Sept. 1913, xxxviii, pt. 1 (no. 149), pp. 144-145, plates viii-xiii, 10 text-figs.
5. The geology of the permo-carboniferous system in the Glendonbrook district near Singleton, N.S.W. *Proc. Linn. Soc. N.S.W.*, 17 Sept. 1913, xxxviii, pt. 1 (no. 149), pp. 146-159, plate xiv, 4 text-figs.
*6. Notes on some recently discovered occurrences of the pseudomorph glendonite. *Proc. Linn. Soc. N.S.W.*, 17 Sept. 1913, xxxviii, pt. 1 (no. 149), pp. 160-168, 6 text-figs.

### Walter George Woolnough, D.Sc.

*Assistant-Lecturer in Mineralogy and Petrology and Demonstrator in Geology*, 1905-1913—

1. Notes on the Geology of West Moreton, Queensland. *Jour. and Proc. Roy. Soc. N.S.W.* 1911, 8 Feb. 1912, xlv, pt. 2, pp. 137, 159. [With R. A. Wearne.]
2. Preliminary note on the geology of the Kempsey district. *Jour. and Proc. Roy. Soc. N.S.W.* 1911, 8 Feb. 1912, xlv, pt. 2, pp. 159-168, plate v.
3. Report of preliminary scientific expedition to the Northern Territory. *Bulletin of the Northern Territory*, no. 1, March 1912. [With others.]

## PATHOLOGY

David Arthur Welsh, M.A., B.Sc., M.D., M.R.C.P. (Edin.).

*Professor of Pathology*, 1902–

1. A contribution to a discussion on serum and vaccine therapy at the ninth Australasian Congress, Sydney, Sept. 1911. *Aust. Med. Gaz.*, 22 March 1913, xxxiii, no. 12 (whole no. 427), pp. 253-255.

1a. ——— *Trans. Aus. Med. Cong.*, 9th session (Sydney 1911), 1913, i, pp. 145-149.

2. Some aspects of vaccination and immunity. *Aus. Med. Gaz.*, 16 Aug. 1913, xxxiv. no. 7 (whole no. 448), pp. 146-148.

3. On the surgical pathology of the large intestine, with special reference to carcinoma. *Trans. Aust. Med. Cong.*, 9th session (Sydney 1911), 1913, i, pp. 145-149.

*3. The intensive specific treatment of epidemic cerebro-spinal meningitis. *Med. Jour. Aus.*, 12 Aug. 1916, ii, 3rd year, no. 7, pp. 113-117. [With W. S. Brown.]

## PHYSIOLOGY

Clement Henry Burton Bradley, M.B., Ch.M. (Syd.), M.R.C.S. (Eng.), L.R.C.P. (Lond.), D.P.H. (Lond.).

*Demonstrator in Physiology*, 1913–

1. Some observations upon the biochemistry of the symbiotic growth of aerogene and anaerogene coliform organisms; with special reference to the combined action of B. typhosus and B. morgan, no. 1, on Mannitol. *Aus. Med. Gaz.*, 1 Feb. 1913, xxxiii, no. 5 (whole no. 420), pp. 97-103.

2. Jottings on the aetiology of organismal disease. *Jour. Syd. Univ. Med. Soc.*, May 1913 n.s. vi, pt. 1, pp. 15-18.

3. A fatal case of appendicitis complicated by spreading cellulitis of obscure clinical and bacteriological nature. *Aust. Med. Gaz.*, 5 April 1913, xxxiii, no. 14 (whole no. 430), pp. 300-301. [With R. S. E. Todd and C. H. Shearman.]

4. Some notes on the symbiotic activities of coliform and other organisms on media containing carbohydrates and allied substances. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 556.

Henry George Chapman, M.D., B.Sc.

*Assistant Lecturer and Demonstrator in Physiology*, 1903-10. *Lecturer and Demonstrator in Physiology*, 1911-12. *Assistant Professor of Physiology*, 1913–

1. A new commutating and reversing key. *Jour. of Physiol.*, xliii, *Proceedings of the Physiol. Soc.*, pp. xxvi-xxviii, 1 fig.

2. Action of the latex of Euphorbia peplus on the photographic plate. *Rept. Aus. Ass. Adv. Sci.* 1911, 23 April 1912, xiii, p. 30. [With J. M. Petrie. Abstract.]

3. A contribution to the study of precipitins. *Rept. Aus. Ass. Adv. Sci.* 1911, 23 April 1912, xiii, p. 298. [Abstract.]

4. On the origin of sulphuretted hydrogen and sulphide of iron in brackish lagoons. *Rept. Aus. Ass. Adv. Sci.* 1911, 23 April 1912, xiii, pp. 688-689. [Abstract.]

5. Technical education for bakers. *Tech. Gaz. N.S.W.*, 1st term 1913, iii, pt. 1, pp. 51-53.

6. Some qualities of a baker's flour. *Aus. Baker and Miller's Jour.*, 29 Nov. 1913, xvii, no. 9, pp. 66-67, 70.

*7. The detection of albumen in human urine. *Med. Jour. of Aus.*, 31 Oct. 1914, i, no. 18, pp. 418-421.

8. On the freezing point of the laked red blood corpuscles of man and some domesticated animals. *Med. Jour. of Aus.*, 3 Oct. 1914, i, no. 14, p. 336.

9. Photographic action of Euphorbia juice. *Engineering*, 20 Nov. 1914, xcviii, no. 2551, p. 611. [Abstract of paper read before B.A.A.S., 1914. With J. M. Petrie.]

*10. Note on the estimation of fat in food for infants. *Jour. and Proc. Roy. Soc. N.S.W* 1914, 15 March 1915, xlviii, pt. 3, pp. 469-472.

11. The action of the juice of Euphorbia peplus on a photographic plate. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 303. [With J. M. Petrie.]

12. On the freezing-point of the laked blood corpuscles of man and some domesticated animals. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 559.

13. The distribution of nitrogen in the seeds of Acacia pycnantha. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, pp. 666-667. [With J. M. Petrie.]

JAMES MATTHEW PETRIE, D.Sc., F.I.C.

*Junior Demonstrator in Chemistry*, 1895-1896. *Caird Research Scholar*, 1904-1905.
*Linnean Macleay Fellow in Bio-Chemistry*, 1907

1. Action of the latex of Euphorbia peplus on the photographic plate. *Rept. Aus. Ass. Adv. Sci.* 1911, 23 April 1912, xiii, p. 30. [With H. G. Chapman. Abstract.]
2. The chemistry of Doryphora sassafras. *Proc. Linn. Soc. N.S.W.*, 26 Aug. 1912, xxxvii, pt. 1 (no. 145), pp. 139-156.
3. Hydrocyanic acid in plants. Part I: Its distribution in the Australian flora. *Proc. Linn. Soc. N.S.W.*, 26 Aug. 1912, xxxvii, pt. 1 (no. 145), pp. 220-234.
*4. Hydrocyanic acid in plants. Part II: Its occurrence in the grasses of New South Wales. *Proc. Linn. Soc. N.S.W.*, 23 March 1914, xxxviii, pt. 4 (no. 152), pp. 624-638.
*5. Note on the occurrence of Strychnicine. *Proc. Linn. Soc. N.S.W.*, 23 March 1914, xxxviii, pt. 4 (no. 152), pp. 761-764.
6. Photographic action of Euphorbia juice. *Engineering*, 20 Nov. 1914, xcviii, no. 2551, p. 611. [Abstract of Paper read before B.A.A.S., 1914. With H. G. Chapman.]
7. The action of the juice of Euphorbia peplus on a photographic plate. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 303. [With H. G. Chapman.]
8. The distribution of nitrogen in the seeds of Acacia pycnantha. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, pp. 666-667.
9. The cyanogenetic plants of New South Wales. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 343.
*10. The chemical investigation of some poisonous plants in the N.O. Solanaceæ. Part ii: Nicotiana suaveolens and the identification of its alkaloid. *Proc. Linn. Soc. N.S.W.* 14 June 1916, xl., pt. 1 (no. 161), pp. 148-151.

SIR THOMAS PETER ANDERSON STUART, K.B., M.D., Ch.M., LL.D. (Edin.).

*Professor of Anatomy and Physiology*, 1883-1890. *Professor of Physiology*, 1890—

1. Demonstration on the dissection of the ox eye-ball, with special relation to Smith's operation for cataract. *Trans. Aus. Med. Cong.*, 9th session (Sydney 1911), 1913, ii, p. 749.
2. The functions of the corpora arantii. *Med. Jour. of Aus.*, 3 Oct. 1914, i, no. 14, p. 333. [Abstract of paper read before the B.A.A.S.]
3. Sound waves. *Med. Jour. of Aus.*, 3 Oct. 1914, i, no. 14, p. 333. [Demonstration before the B.A.A.S., of apparatus showing how the air particles move in transmitting sound.]
4. The cyclograph. *Med. Jour. of Aus.*, 3 Oct. 1914, i, no. 14, p. 333. [Demonstration, before the B.A.A.S., of an instrument for quickly marking particular portions of microscopical specimens.]
5. The action of the stapedius muscle. *Med. Jour of Aus.*, 3 Oct. 1914, i, no. 14, pp. 333-334. [Abstract of note read before the B.A.A.S.]
6. The action of the intercostals. *Med. Jour of Aus.*, 3 Oct. 1914, i, no. 14, p. 334. [Abstract of a communication, made to the B.A.A.S., on the fixation of the thorax in forced and in delicate movements.]

HENRY SLOANE HALCRO WARDLAW, D.Sc.

*Science Research Scholar in Physiology*, 1913-1915. *Junior Demonstrator in Physiology*, 1915-1916
*Linnean Macleay Fellow in Physiology*, 1916

*1. On the accuracy of Neumann's method for the estimation of phosphorus. *Jour. and Proc. Roy. Soc. N.S.W.* 1914, 12 Aug. 1914, xlviii, pt. 1, pp. 73-93.
*2. On the nature of the deposit obtained from milk by spinning in a centrifuge. Preliminary communication. *Jour. and Proc. Roy. Soc. N.S.W.* 1914, 25 Nov. 1914, xlviii, pt. 2, pp. 152-171.
*3. On the diffusible phosphorus of cow's milk. *Jour. and Proc. Roy. Soc. N.S.W.* 1914, 25 Nov. 1914, xlviii, pt. 2, pp. 253-266.
4. Note on the deposit obtained from milk by spinning in a centrifuge. *Rept. Brit. Assoc. Adv. Sci.* Australia 1914, 1915, p. 556.
*5. The temperature of Echidna aculeata. *Proc. Linn. Soc. N.S.W.*, 15 Sept. 1915, xl. pt. 2, pp. 231-258, 8 figs.
*6. On the composition of human milk in Australia. Part I. The composition during the early stages of lactation. *Jour. and Proc. Roy. Soc. N.S.W.* 1915, 15 Nov. 1915, xlix, pt. 2, pp. 169-198. 1 fig.
7. Carbon dioxide in expired air. *Med. Jour. of Aus.*, 6 May 1916, i, 3rd year, no. 19, p. 387.

# NEPHELINE-BEARING ROCKS.

# PRELIMINARY NOTE ON THE NEPHELINE-BEARING ROCKS OF THE LIVERPOOL AND MOUNT ROYAL RANGES.

By W. N. BENSON, B.Sc.

With Plates VI, VII.

[*Read before the Royal Society of N. S. Wales, August 2, 1911.*]

ABOUT two years ago, when first in the Nundle district, the writer noticed the great abundance, in the gravels of the Peel River, of pebbles of a remarkable coarse-grained basic rock with large dark purple-brown phenocrysts of augite. An examination of slices of these under the microscope showed that the augites were strongly zoned, sometimes having the hour-glass structure, and were highly titaniferous, while there were a number of large apatite prisms. The general facies strongly recalled the famous nepheline dolerite of the Löbauer Berg in Saxony. Nevertheless no nepheline was detected, the salic mineral being labradorite. Similar rocks were found later at Crawney, probably *in situ*, some fourteen miles further up the river than Nundle. Want of time prevented the investigation of their field relationships. While on a brief visit to Goonoo Goonoo, a small pipe of the rock was found forming a slight elevation (Currajong Hill) about a mile south-east of the station. A further large extension of these rocks was suggested by the following observation made by Mr. E. C. Andrews:—"At the Hunter and Manning River headwaters two distinct basaltic types occur, one a holocrystalline rock with large augite crystals so abundantly scattered throughout its mass as to obtain for it locally the name of 'plum pudding stone.' Other types found here are dense fine-grained vesicular olivine basalts."

[1] Tertiary History of New England, Rec. Geol. Surv. N.S.W., Vol. VII, pt. 3, p. 63, 1903.

Some months later on examining a collection of rocks given by Mr. Eustace Wilkinson of Pokolbin near Maitland to Mr. R. E. Priestley, F.G.S., a similar porphyritic rock was found, and, on sectioning, abundant nepheline was clearly visible. In letters from Mr. Wilkinson I learn the following particulars: The rocks occur in a large series, stretching from Stewart's Brook to the Barrington Trigonometrical Survey Station, a distance of 10 miles. They appear everywhere to overlie a dense normal olivine basalt, and this in turn overlies steeply dipping cherts, sandstones, and shales, carrying such typically Carboniferous forms as *Orthotetes crenistria*, *Spirifera striata*, *Orthonychia*, *Capulus* cf. *Oehlerti*, De Kon., with abundant crinoid stems. The fossils were kindly determined by Mr. W. S. Dun in specimens forwarded by Mr. Wilkinson.

The section exposed on the Barrington Trig. as observed by Mr. Wilkinson, is shown in fig. 1. He remarked, however, that it was drawn from memory, and that it had been possible to devote but a short time to its examination. And further, that as it was chiefly rocks of rather unusual appearance that he collected, normal basaltic rocks were sometimes passed over. Nevertheless he is emphatic on the highly important observation that the coarse-grained dolerites overlie normal olivine basalts.

A final visit proved that rocks of this type occurred near Nundle. They cap Square Top Hill, which lies three miles to the west of the township, and under the microscope prove to contain abundant nepheline.

There is evidently here a field of great extent geographically, (Stewart's Brook and Nundle are more than forty miles apart), and of considerable interest petrographically, see fig. 2. In view of the writer's approaching departure for England, it was thought well to collect into a brief note the scanty data available on these rocks to direct attention to their occurrence.

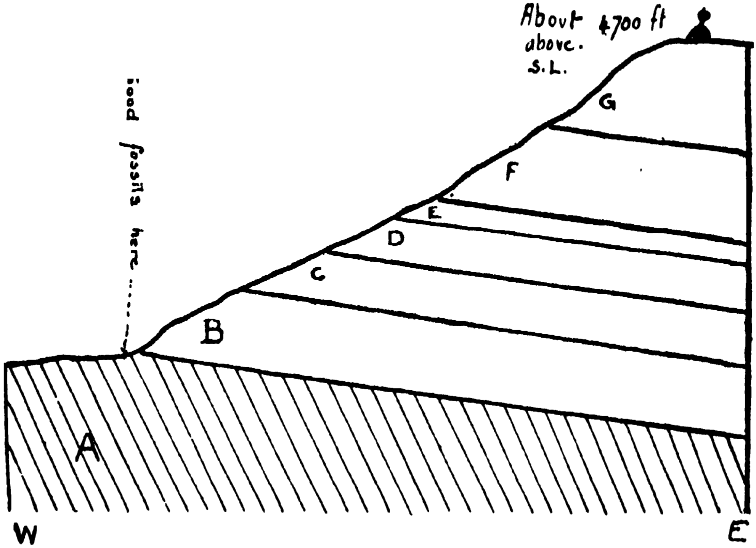



Fig. 1. *Sketch section of Barrington Trigonometrical Station Hill based on observations and collections made by Mr. Eustace Wilkinson.*

*A*. Carboniferous sandstone slates, shales and conglomerates, dipping in a general easterly direction at from 20° to 86°

*B*. Dense olivine basalt with large phenocrysts of olivine; about 500 feet thick (Rock No. 1).

*C*. Olivine dolerite (Rock No. 2) with natrolite. The most persistent rock of the district, always overlying the basalt. It merges into the theralites. About 300 feet thick.

*D*. Theralite of varying grain size and degree of zeolitisation (Rocks No. 3 and 4). It always overlies the finer grained No. 2 rock. About 200 feet thick.

*E*. Olivine dolerite (No 2 Rock). About 100 feet thick.

*F*. Basalt, very decomposed, with vesicles filled with natrolite and analcite. Made up of numerous flows. About 500 feet thick.

*G*. Olivine dolerite with a little theralite.

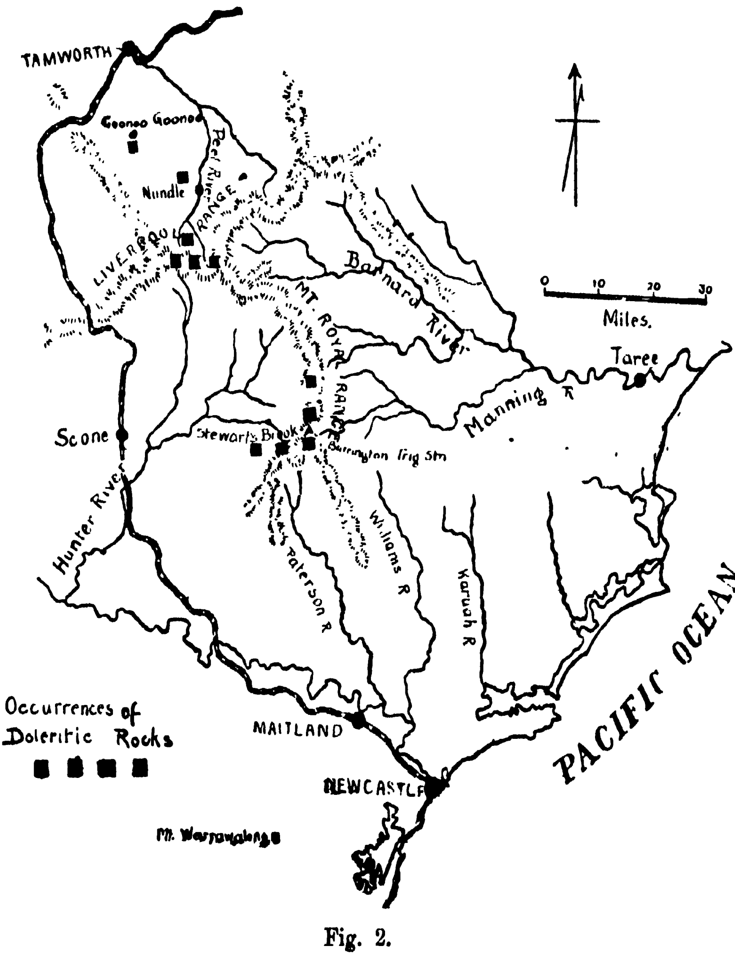



Fig. 2.

Petrologically the rocks may be termed dolerites, using the term in its widest possible sense. They are holocrystalline aggregates of augite and plagioclase with large ilmenite crystals occasionally developed, but owing to the presence or absence of olivine, orthoclase, and nepheline, and the variation in texture, they may fall into the more strictly defined divisions of the olivine dolerites, the essex-

ites, the theralites and the basanites. The most remarkable rocks are the theralites (Nos. 3 and 4 of Mr. Wilkinson's figure) that occur on the slopes of Barrington Trig. These two rocks differ only in grain size and amount of zeolite developed. They are very coarsely granular with exceedingly well marked zonary structure in their deep purple augites. The predominant salic mineral is a labradorite in tabular crystals, and there are also large crystals of ilmenite and prisms of apatite. In addition to this, there is a certain amount of clear nepheline. All these different minerals can readily be distinguished with the naked eye in the slide of No. 4, of which *Plate 6*, fig. 1 is a photograph. In addition, there is a small amount of zeolite developed by alteration of the nepheline.

The most interesting feature, perhaps, is the occurrence of a second generation of augite of a more greenish tint than that of the phenocrysts, and this forms a granophyric intergrowth with the nepheline, either in little hooked-like pieces fig. 3 (a), or in peculiar arrow-head shapes fig. 3 (b).[1]

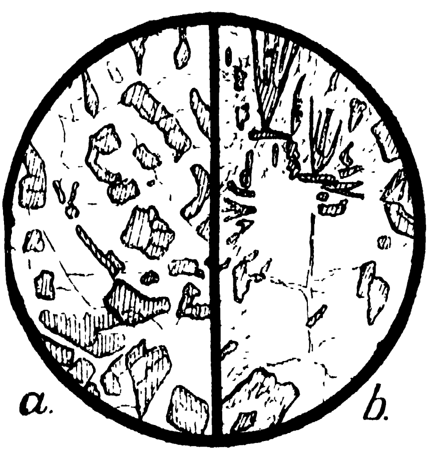



Fig. 3. *Graphic intergrowths of augite shaded, and nepheline clear, in theralite.*

(*a*) from Stewart's Brook, magnified 80 diameters.

(*b*) from Barrington Trigonometrical Station hill, magnified 22 diam.

*This is an enlarged drawing of the large nepheline grain visible in the centre of fig 1, Plate 6.*

[1] Cf Fig. 89 B, A. Harker, The Natural History of Igneous Rocks, p. 271.

This intergrowth of augite and nepheline, though not unknown, is a very rare petrological feature. It is developed in the Löbauer Berg rock above mentioned to a finer degree than here figured. In the Stewart's Brook rock there are small aggregates of chlorite, probably pseudomorphous after olivine, but these are absent from the Barrington rock. This type of rock seems best classed as a theralite. The low percentage of silica suggested by the abundance of nepheline is confirmed by the fact that a determination of silica showed the presence of 42·54% only.

No. 2 of the Barrington series, which Mr. Wilkinson remarks appears to pass by transitions into the other types (3 and 4), has a very different fabric, the tabular plagioclases having a more parallel arrangement (fig. 2, *Plate 6*). There seems to be no definite nepheline, but there are present, interstitially, cloudy areas of a very low refractive index, which may represent altered orthoclase, though the occasional presence in them of spherulites of natrolite suggests the possibility of the derivation from nepheline. The augite occurs in large irregular grains with a slight development of the ophitic structure. The presence of numerous small inclusions of olivine and felspar gives it a curiously pitted appearance. Olivine also forms numerous large idiomorphic crystals. Ilmenite is abundant in small plates, but apatite is rare.

In the majority of the doleritic pebbles of the Peel River gravels, the structure is rather intermediate between those of the rocks described above. The tabular felspars have not much parallel arrangement, the augites are varied in the extent to which they show ophitic structure or idiomorphism, but are always purple. Olivine is abundant, ilmenite frequent in small grains, and apatite is not very common. In one instance orthoclase is present, forming interstitial intergrowths with plagioclase, and occasionally

occurs in individual grains. It is in very small amount however. Nepheline does not seem to be present in any of the slides I have examined.

Two extreme types call for special notice. The exceedingly coarse-grained rock illustrated in *Plate 7*, is composed of large crystals of augite up to two centimetres in diameter, with smaller crystals of olivine and plagioclase. There are also small crystals of ilmenite and apatite. Between the large crystals is a little fine-grained ground-mass composed of tiny felspar laths, some of them possibly sanidine, and pale yellow-brown masses of a platy zeolitic material, the precise nature of which must be left for future examination. Here and there are aggregates of very minute graphic crystallisations and rods of brown-grey augite of the second generation. This is very similar in many respects to the augite that is intercrystallised with the nepheline of the rocks described above. The rock must provisionally be classed as a porphyritic olivine dolerite. The same name is to be applied to a rock of a very different appearance, namely, that figured in fig. 3, *Plate 6*. It consists of large phenocrysts, up to 4 millimetres in diameter, of augite and olivine, set in an almost basaltic ground-mass composed of abundant small grains of ilmenite and purple augite with felspar laths. A little of the yellowish zeolite is present, and a very few small olivines. There appears to be a third generation of minute brown-grey arrow-heads and needles of pyroxene developing interstitially.

The only definitely nephelinic rock yet found near Nundle is that from Square Top. It forms a capping two hundred feet thick on the summit of the hill, but its mode of occurrence was not proved. There were apparently no underlying Tertiary gravels. In hand specimens the rock is dark grey, with dark purple-brown augites, and on weathered surfaces white felspar laths can be distinguished. Its microscopical

appearance is shown by fig. 4, *Plate 6*. It is seen to contain large, perfectly developed, phenocrysts of purple augite which have often an exterior zone full of minute inclusions of ilmenite, olivine, and scraps of plagioclase, giving a very pitted appearance. Usually the colour changes from strong purplish pink on the inner portion of this zone, to greenish-grey on the outer portion. These phenocrysts are up to three millimetres in diameter. There are numerous smaller phenocrysts of olivine. The ground-mass consists of short felspar laths, many of which are sanidine, and abundant hexagonal prisms of nepheline. A good deal of this has been changed into natrolite. As this rock has a much finer grain than any of the others and a far more volcanic habit, it may be termed a nepheline basanite. The small amount of plagioclase present prevents it from falling directly under the nepheline basalts, using the term in its strict sense.

A mile south-east of Goonoo Goonoo Station and about twenty miles north-west of Nundle is a small knoll, Curra-jong Hill. On a very hasty examination it appeared to be a neck about ten yards (from memory) in diameter composed of a coarse grained rock of granite texture with dark purple black pyroxene. On section, this proves to be also closely related to the rocks above described. It is a remarkably fresh rock, and contains large purple augites, clear olivines, large labradorite tabulae, with a fair amount of interstitial orthoclase. Numerous small crystals of ilmenite are present, often surrounded by bright red-brown pleochroic biotite. Apatite prisms are well developed. The rock is best termed an essexite.

Here attention should be drawn to the similarity, several times remarked upon by Dr. Jensen,[1] between these rocks and the essexites, described by him, which occur as rolled

[1] Proc. Linn. Soc. N.S. Wales, Vol. xxxii, p. 883, 1907.

pebbles in Bullawa Creek in the Nandewar Mountains, over one hundred miles N.N.W. of Nundle and Goonoo Goonoo.

With the exception of Mr. Wilkinson's important discovery that these rocks overlie the normal Tertiary olivine basalt, and the writer's discovery of them at Nundle capping a high hill, we have little direct evidence of their mode of occurrence. Nevertheless an observation made by Dr. Woolnough is of importance in this question. He ascended Mount Warrawalong thirty miles W.S.W. of Newcastle and over a hundred miles south of the occurrences described above. He there found the Tertiary basalt cap penetrated by dykes of coarse-grained olivine dolerite. He has generously handed specimens of this rock to me for description.

Microscopically the rock is seen to contain large elongated ophitic crystals of dark purple augite up to two centimetres in length, with felspar tabulæ and interstitial white zeolite. The microscope shows that the augite is strongly titaniferous, and has the hour-glass structure developed to some extent. A peripheral zone of a greenish colour is sometimes developed, the colour-change being usually gradual, though in some instances quite sharp, as though the crystal had grown by secondary enlargement during a later epoch of pyroxene crystallisation. The felspar is chiefly orthoclase, in large or smaller prismatic crystals, idiomorphic against a yellowish zeolitic ground mass. It is mostly glassy and untwinned, but decomposition is commencing along the cracks. Plagioclase tabulæ are also present. The refractive index is distinctly above that of the Canada balsam.* There are large crystals of olivine, irregular plates of ilmenite, slightly leucoxenised, and numerous large apatite prisms. Interstitially there is a considerable amount of an almost isotropic yellowish zeolitic material, (analcite?), like that in the northern rocks. Imbedded in this are minute graphic fragments of green augite, similar

to that on the periphery of the phenocrysts. There are also, interstitially, patches of minute plagioclase laths with ophitic green pyroxene. This feature also is exhibited in some of the northern rocks. There are a few large patches of a zeolite of moderate birefringence. This rock is clearly an essexite. A second rock from the same locality and occurrence differs in the almost complete absence of orthoclase. The plagioclase is labradorite, and there is a little yellowish interstitial material with minute felspar laths and augite of the second generation; apatite is rare. This is an olivine dolerite. It is possible, of course, that the essexite is not a distinct occurrence, but that the section examined chanced to pass through a locality of orthoclase segregation in the essexitic dolerite.

It will be seen that the specimens bear features strongly recalling the northern rocks and may be considered to belong to the same series. Their intrusive character into Tertiary basalts supports Mr. Wilkinson's statement that the latter overlie these at Stewart's Brook. The extreme coarseness of grain of the majority of the rocks makes it in the highest degree improbable that they were flows. Might it not be suggested that they will be found to form sills in the Tertiary basalt, and to be comparable to the dolerite sills in the Tertiary igneous series of Skye? It may further be pointed out that the range of mineralogical composition of these rocks is almost paralleled by that of the Tertiary basalts themselves. Some are purely felspathic, some strongly nephelinic.

I have to thank Mr. Eustace Wilkinson for the pains he has taken in supplying me with information and specimens from Stewart's Brook and the Barrington Trig., and Dr. Woolnough for the opportunity of examining the Warrawalong material. To Mr. A. B. Walkom, B.Sc., I am indebted for kindly consenting to correct the proofs in my absence.

## Explanation of Plates.

Plate VI, fig. 1—Theralite from Barrington Trigonometrical Station. Note the zoned augite, large ilmenites, cloudy felspar and clear white nepheline × 4. An enlarged drawing of this white patch is shown in text fig. 3.

„ 2—Olivine dolerite from the above locality, with plagioclase, augite, olivine, and natrolite × 12.

„ 3—Olivine dolerite from the Peel River gravels showing basaltic ground-mass × 11.

„ 4—Nepheline basanite, Square Top, Nundle, showing augite phenocrysts, with peripheral zone full of inclusions, olivine, and hexagonal nepheline crystals in the ground mass × 18.

Plate VII, Specimen of porphyritic olivine dolerite from the Peel River gravels near Nundle, with large phenocrysts of titaniferous augite. Scale one half natural size.

Corrigendum to paper entitled "The Volcanic Rocks of Hornsby and Dundas," this Journal, Vol. XLIV, pp. 495 – 555, 1910. The analysis of the Hornsby basalt, pp. 544 – 545 was made simultaneously with analyses of several other rocks, and it has since been discovered that the wrong figure for titanic oxide was entered through oversight, in the Hornsby analysis. A redetermination has been completed and the correction must be made as under.

Pages 544 and 545, substitute for the figures given:—

$Al_2O_3$ 17·94% $TiO_2$ 2·64%,

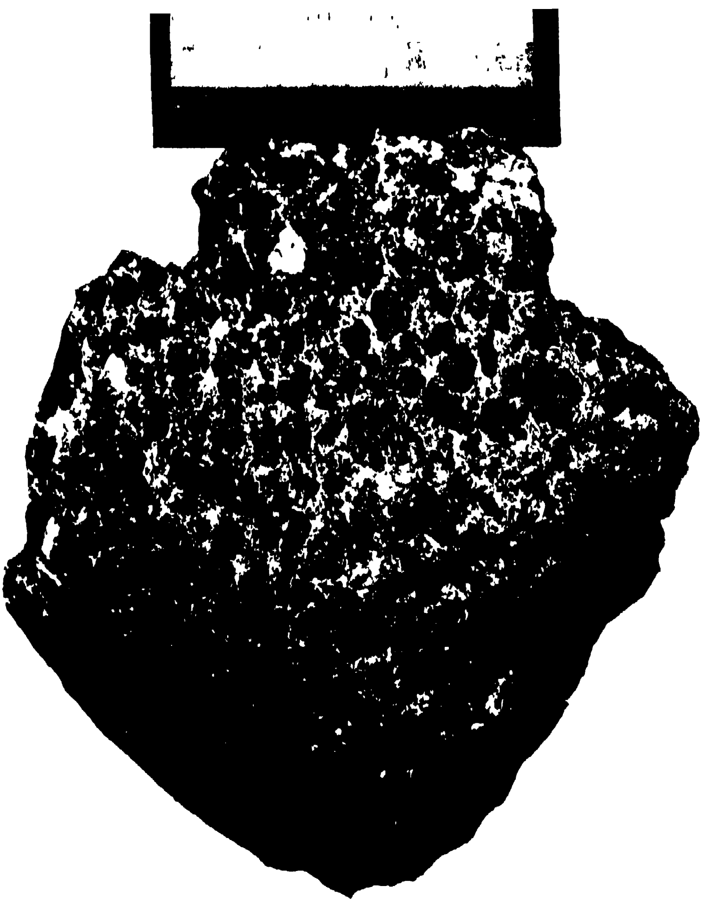
and the following recalculated norm.:—

| | | | |
|---|---|---|---|
| Orthoclase | 13·34 | Magnetite | 4·64 |
| Albite | 31·44 | Ilmenite | 5·02 |
| Anorthite | 24·74 | Apatite | 1·34 |
| Nepheline | 1·14 | $CO_2$ | 71 |
| Diopside | 9·95 | Water | 4·12 |
| Olivine | 4·54 | | 100·98 |

1.

2.

3.



# Note Descriptive of a Stereogram of the Mount Lofty Ranges, South Australia.

By W. N. Benson, B.Sc.

[*From "Transactions of the Royal Society of South Australia," vol. xxxv., 1911.*]

[Read August 10, 1911.]

Plates XX. and XXI.

In a previous paper a short outline was given of the physiography of the Mount Lofty Ranges as it appeared to the writer from observations made during 1908.(1)

Recently a stereogram has been constructed for the Sydney University to illustrate the features on which his conclusions were based. A brief description of this model may not be out of place here. The information on which it was modelled was obtained from the official map of south-eastern South Australia and the topographic map of the vicinity of Adelaide. Trigonometrically-determined heights are sadly few in number. The general relief of the area between Noarlunga, Angaston, and Murray Bridge, and in the Inman Valley is based on the writer's own sketches and aneroid readings. A topographic map of Mount Barker district published in the daily Press during the military manœuvres of 1908 was also of service. The modelling of the area about Mount Compass is based on Mr. Howchin's map and descriptions (2) and additional information kindly supplied by him.

Owing to the writer's non-acquaintance with areas outside these limits the model may be subject to some modification in those parts, and indeed owing to the smallness of scale no more than a very rough accuracy has been attempted throughout.

The small inset model illustrates the main tectonic features. As these are being investigated in detail by Mr. Howchin a very brief description will here suffice.

The main portion of the Mount Lofty Ranges, stretching from beyond Angaston to Cape Jervis and extending into Kangaroo Island, is a peneplain. The main drainage, before uplift, was in mature valleys running in an approximately meridional direction.(3) On the peneplain surface were residuals of a higher level, monadnocks, such as Mounts

(1) Trans. Roy. Soc., S.A., 1909, p. 107.

(2) Trans. Roy. Soc., S.A., 1910, pp. 231-47 and pls. xxxi to xlv.

(3) W. Howchin, Geography of South Australia, p. 124.

Lofty and Barker, composed of a resistant rock, usually quartzite. In comparatively recent, probably at the close of Pliocene, times this peneplain was elevated, by upthrust chiefly, rather than by folding.[4]

Stratigraphical proof of this uplift is afforded by the presence of raised marine Eocene fossils[5] on the hills behind Encounter Bay, at the head of the Hindmarsh River,[6] where they occur at an altitude of 1,000 ft.

Mr. Howchin has also noted the presence of steeply dipping and overfolded Tertiary beds near Sellick's Hill.[7] By this movement the drainage was much altered. Erosion readily removed the soft glacial clays and sandstones from the Inman, Hindmarsh, and Upper Finniss Valleys, and in the first named exposed in places the hard glaciated Permo-Carboniferous land-surface.[8]

The uplift was not *en bloc*, but the area was broken up into larger and small blocks which were differentially elevated, tilted to some extent, and possibly slightly flexed. This makes fault scarps a frequent feature.[9] The small inset model shows the series of fault-blocks that form the western flanks of the range. They are roughly triangular in shape and are tilted sloping to the south. They may be due to differential elevation in the first instance or may have dropped off the main peneplain, collapsing after their original uplift.

A somewhat similar series of steps, though less well marked, appears on the eastern flanks of the Range, as at Palmer and the Bremer Range. It is possible that Mount Lofty and perhaps the Forest Range are on a block raised above the general level, of which German Town Hill would be the eastern scarp. This feature is not shown on the model, however, chiefly because it has not been sufficiently studied by the writer.

Backstairs Passage, the narrow strait that separates Kangaroo Island from the mainland, may have originated in one of two ways. There can be little doubt that the high flat surface of the island is a continuation of the peneplain of the

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(4) Compare R. Tate, Trans. Roy. Soc., S.A., 1884-5, pp. 56-7; also E. C. Andrews, Geographical Unity of Eastern Australia, Proc. Roy. Soc., N.S.W., 1910, especially p. 440.

(5) R Tate, Proc. Roy. Soc., N.S.W., 1888, p. 242.

(6) W. Howchin, Trans. Roy. Soc., S.A., 1898, p. 15-6; also present volume *ante* pp. 55-6 and pl. x. (inset).

(7) See present volume, *ante*, pp. 47-59.

(8) W. Howchin, Report of the Australasian Association for the Advancement of Science, 1907, p. 267; also Trans. Roy. Soc., S.A., 1910, p. 1 and p. 231.

(9) W. Howchin, present volume, p. 53.

mainland. That its extension is in a westerly direction rather than southerly, parallel to the Mount Lofty Ranges, cannot be due primarily to the original Palæozoic folding, the axis of which also bends in a similar fashion; but it may be due to it, secondarily, in that the bounding fault-scarps have developed parallel to the folding planes of the rocks, as in the case of the Mount Lofty Range itself. The most obvious explanation of the passage is that it is a senkungsfeld, *i.e.*, an area dropped down between two fault-planes, respectively the southern scarp of the main range and the northern of the island. The Pages might be considered as the tops of a sunken residual. But in the case of the Inman, Hindmarsh, and Upper Finniss Valleys it is clear that their great maturity is due to the fact that they were carved by the Permo-Carboniferous glaciers and filled with their soft till. This has been quickly removed when first exposed to the attack of streams, rejuvenated by the uplift. Might it not also be suggested that the Backstairs Passage was a wide glacial valley filled with till, which has been subsequently almost entirely removed by stream and marine erosion? Several facts are in support of this. The base of the valley must, of course, have been below sea-level; but so is that of the Inman glacier at Victor Harbour The researches of Mr. Howchin [10] have shown the strongly glaciated nature of portion of the southern scarp of the mainland, and he has proved the presence of glacial boulders near Cape Jervis.[11] He has also described Permo-Carboniferous glacial till on northern Kangaroo Island.[12]

The depression is thus bounded on both sides by glacial material and, in places, striated surfaces facts strongly in support of the second hypothesis. It is, of course, possible that block-faulting may have assisted in the formation of the passage, but the author's inclination is to give it a minor rôle. On the glacial hypothesis The Pages should be roches moutonnées. The Admiralty soundings are of little help in deciding the question, as they show only that a flat bottom exists in the passage at a depth of less than 20 fathoms

The drainage alterations during the various periods of earth movement require much further study. Rivers were captured, as the heads of the Onkaparinga by the Torrens,[13]

(10) Trans. Roy. Soc., S.A., vol. xxxiv., 1910, p. 1, pls. i. to xvii.

(11) Rep. Aus. Asso. Adv. Science, vol. vii., 1898, p. 124

(12) Trans. Roy. Soc., S.A., vol. xxiii., 1899, p. 198, pls iv. and v.

(13) This conclusion, though reached independently by the writer, has been, he finds, Mr. Howchin's view for some time

or revived with the formation of valley in valley structure, as in Foreston Creek, near Gumeracha; or they were reversed altogether. Sixth Creek, flowing north from Uraidla into the Torrens, seems to be a reversal of Cox's Creek flowing south into the Onkaparinga. Further, the uplift and consequent entrenchment and headward extension of the east and west valleys (entrenched meanders of the Torrens River) brought about the capture and reversal of portions of the meridional streams. An excellent example of this was noted in Millendella Creek, near Palmer, by Mr. Howchin and the writer. The former has a full description of it in preparation. Other examples are shown by Rocky Gully,[14] near Murray Bridge, Mount Barker Creek, Bull's Creek, etc. The recurrence of earth movements at several periods probably accounts for many puzzling features in the present drainage, particularly the course of the Lower Onkaparinga. The occurrence of its present valley cutting across the middle of the southward sloping, Clarendon-Aldinga block, is very remarkable. Mr. Howchin has shown that an older mouth lies considerably south of its present opening.[15]

Many further problems await solution in this area, which is one of the most interesting geologically and physiographically in Australia.

The writer's thanks are due to Mr. Howchin for his ever-ready assistance and information freely given.

Geological Department,
Sydney University,
March, 1911.

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## DESCRIPTION OF PLATES.

### PLATE XX.

Stereogram of the Mount Lofty Ranges.

### PLATE XXI.

Map of the Mount Lofty Ranges to show the drainage system. Notice how the original meridional drainage, the streams of which are in matured valleys, has been broken into numerous watersheds by capturing east and westerly gorges, developed consequent upon the uplift of the range. Mark particularly the Wakefield, Light, Rhine, and Onkaparinga systems and their relation to the lines of faulting. These faults have an easterly downthrow on the eastern side and a westerly on the western. The ends of the fault-lines shown are points beyond which they have not been traced, or appear to pass into monoclinal folds, or to die out. The doubt as to the scarp nature of the southern coast is explained in the text.

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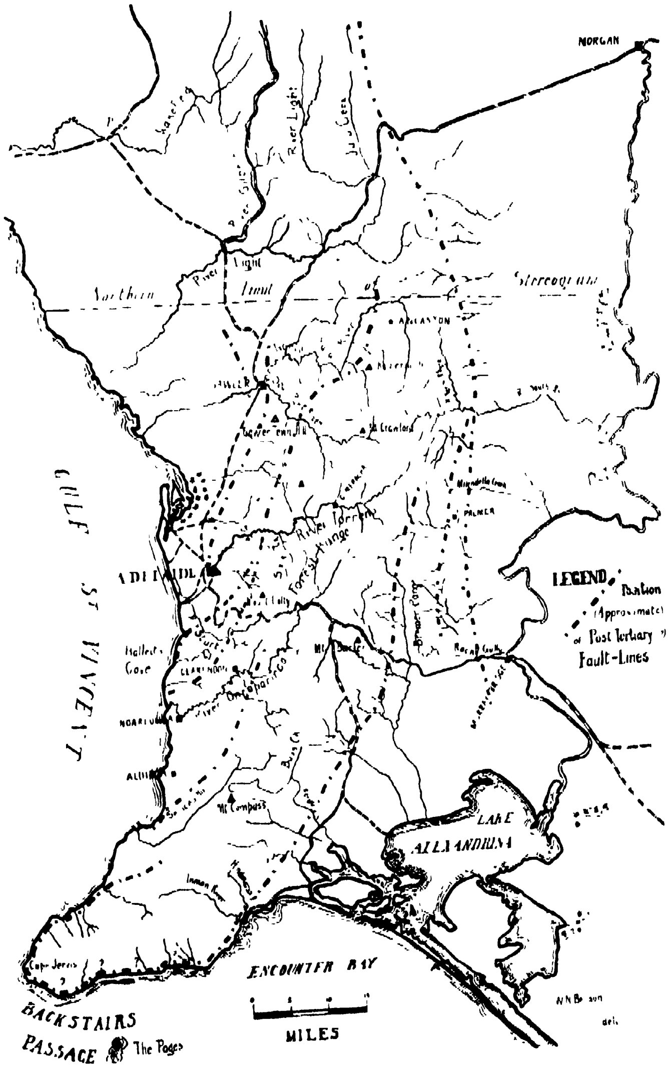
(14) W. G. Woolnough, Trans. Roy. Soc., S.A., 1908, p. 124.

(15) Geography of South Australia, p. 124.

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[*From the Proceedings of the Linnean Society of New South Wales, 1914, Vol. xxxix., Part 3, August 26th.*]

# PETROLOGICAL NOTES ON VARIOUS NEW SOUTH WALES ROCKS.

By W. N. Benson, B.A., B.Sc., F.G.S., Linnean Macleay Fellow of the Society in Geology.

## i. *Rocks of Nullum Mountain, near Murwillumbah.*

Some years ago, the writer spent a day at Murwillumbah, and examined Nullum Mountain, which lies five miles to the south-west of the town. Nothing yet has appeared concerning the geology of this area, so that a few notes may be given here to call attention to the spot. The mountain forms a short ridge, standing prominently in front of the range. Its relief is due to the presence of an inclined sheet of granophyre, which dips towards the north. The main mass of the mountain is composed of gnarled slaty rocks of the Brisbane Schists, of Lower Palæozoic or even earlier age. The inclined sheet outcrops on the southern side of the ridge, and is exposed on the northern slopes of the mountain for some distance down its face. At the base, various dykes have been noted. The sill consists chiefly of granophyre composed of small crystals of orthoclase and acid plagioclase, partly allotriomorphic, partly idiomorphic, surrounded by a granophyric intergrowth of quartz and orthoclase. A little biotite occurs and magnetite, but the bulk of the ferromagnesian constituents are altered into regular patches and spherulites of chlorite, and grains of epidote. A few apatite crystals are also present.

The rock of the upper surface of the sheet exposed on the north slope shows frequently no granophyric structure, but has a trachytic habit. It consists of a pilotaxitic felt of felspar-laths, both orthoclase and acid plagioclase, and frequently an untwinned felspar of the same refractive index as Canada balsam, possibly anorthoclase, together with a fair amount of interstitial quartz. The

pyroxene is a normal grey augite, forming small prisms more or less altered to chlorite and epidote, magnetite and ilmenite in small grains and plates. Xenocrysts are present, that seem to have been derived from a dolerite: they may occur aggregated or singly, and are rather corroded. The basic plagioclase is being replaced by irregular patches of albite; the pyroxene is a grey augite, with a basal striation and varying optic axial angle, sometimes large, but in two instances almost 0°. This indicates that it is an enstatite-augite. Large plates of ilmenite occur also. The vesicles of the rock are filled with quartz and chlorite.

The majority of the dykes on the north face of the mountain are trachyandesites, related to the last rock. They are fine-grained green rocks, showing phenocrysts of plagioclase and orthoclase in a matrix of laths of the same minerals. The coloured constituents have been largely decomposed, but are sometimes seen to be minute prisms of grey augite, with rarely large chlorite-pseudomorphs after the same mineral; the extinction-angle of these pyroxenes is quite high; alkaline pyroxenes or amphiboles are not recognisable. Magnetite occurs in large and in very minute grains. Considerable variation is seen in the grainsize of the ground-mass, and in the proportion between the potash and lime-soda felspar, the decrease in the former indicating a passage towards the andesites.

A quite different type of dyke occurs in a road-cutting near the foot of the mountain, adjacent to one of the more basic green dykes. It consists entirely of colourless minerals, being a very fine-grained mixture of andesine, quartz and a minor amount of orthoclase, with a few small phenocrysts of quartz and andesine. The rock is much obscured by sericite.

One cannot be certain yet of the affinities of these rocks. From a macroscopical examination of the writer's collection, Dr. Jensen* considered that they might be riebeckite-trachytes, and he himself found dykes of alkaline trachyte in the neighbourhood of Murwillumbah; the microscopical study, however, has not confirmed the presence of riebeckite.

* Report Aust. Assoc. Advt. of Science, 1911, p.193.

It may be suggested that the suite is related to the granophyres and andesites of the West Moreton District, described by Messrs. Wearne and Woolnough†. The latter has found a very interesting igneous complex to occur associated with the andesitic mass of Mount Warning, adjacent to Nullum Mountain.‡ A rich field of discovery awaits the petrological investigator in this district.

ii. *Inclusions in a dyke at Gerringong.*

The dyke under consideration occurs on the beach at Gerringong, and is recorded as No. 16 in Mr. Harper's list*. It splits up into overlapping lenticular branches. In places, the rock is full of steam-cavities, which are arranged in bands parallel to the boundaries of the intrusion. Here and there are inclusions in the volcanic rock, at one spot so abundant as to make up nearly half the bulk of the rock. About thirty slices of these have been studied, with the results here presented. The dyke-rock itself is a basalt, consisting of idiomorphic prisms of purple augite and laths of labradorite, with a fine even grain-size. As accessory constituents are present magnetite, small brown pleochroic crystals of hornblende, and very minute needles of apatite. No glass is to be seen. Chlorite and epidote are present in varying amount.

The rocks of the inclusions are derived from a gneissic complex, that must lie at great depth below the present surface (Upper Marine Permo-Carboniferous rocks). They consist of alkali-felspar gneisses and quartz-schists, with a few gabbroid rocks. Interesting features are brought about by the partial melting and absorption of the inclusion in the basalt-magma, some of which recall the observations of Lacroix on the granite-xenoliths in the basaltes of the Auvergne.

The best preserved gabbro was obtained by Mr. Aurousseau, who kindly permitted me to study it. It is a coarse-grained rock consisting chiefly of labradorite. The augite is in large ophitic grains, and slightly chloritised. Magnetite is also present. Another

† "Notes on the Geology of West Moreton, Queensland." Proc. Roy. Soc. N. S. Wales, 1911, pp. 137-159.

‡ Verbal communication.

* Rec. Geol. Surv. N. S. Wales, 1905, Vol. viii, Pt. 2, p. 105; also Plate xix.

specimen is of medium grain-size, and is composed of labradorite, subophitic augite, abundant magnetite and a little quartz. The augite has a peculiar spongy habit, containing felspar in irregular patches and numerous schiller-magnetites. Here and there, in irregular bays cutting across the large crystals, are patches of fine-grained lathy felspar, small augite, ilmenite, and magnetite-grains, with a general basaltic appearance. In such areas, there is sometimes a regular arrangement of the magnetite, as if pseudomorphous after a former crystal. These structures, together with the spongy nature of the augites, suggest a partial recrystallisation of the rock under the heat of the surrounding basalt-magma. The large amount of decomposition-products in this rock greatly hinders its elucidation.

The inclusions of the metamorphic series are of several kinds. One is an alkali-felspar gneiss, consisting of microperthite, orthoclase, quartz, and a very little plagioclase. It has a blastogranitic structure, and the quartz shows, very strongly, marked strain-effects. Another type contains, with orthoclase, a considerable amount of andesine. A third type has a very gneissic structure, and consists of abundant quartz, andesine, a little orthoclase, diopside and sphene; its composition is, therefore, that of a type of granodiorite. There are, in addition, numerous fragments of felspathic quartz-rocks. Several of these are very coarse-grained and poor in felspar, resembling crushed vein-rock. The others are altered quartzites, and are more or less felspathic Both are greatly crushed, with occasionally long mylonitic streaks, which lie along the direction of crystalloblastic schistosity or obliquely to it. The crystalloblastic structure is very pronounced; the felspar of the vein-rocks is in large plates; that of the schists proper is disseminated in small grains throughout the rock.

The contact-effects may be divided into absorption, melting and recrystallisation, and these occur frequently in association. The first is well seen on the actual contact of an inclusion with the basalt. The difference betwen the boundaries of the quartz-grains and the felspars is most striking. As is usually the case, there is a strong reaction-rim developed round the corroded surface of the

quartz, and this rim consists of minute colourless prisms of diopside. Around the felspar, no such rim exists; this mineral appears to have been absorbed into the basalt-magma much more quickly than the quartz-grains, which project out from the general boundary of the inclusion into the basalt or are even isolated in it. The single instance of a pyroxene-bearing gneiss shows how much less readily is the pyroxene absorbed than the felspar. It has been shown that this order of solubility holds also in the case of the basic felspar and augite of the gabbroid inclusions of Dundas.*

The rocks with glass are few in number. In the granodiorite, it occurs in irregular dull-brown patches, more or less cryptocrystalline with sometimes slag-like skeleton-crystallites, sometimes penetrated by laths of secondary felspar growing in from the felspar that forms the boundary to the droplet of glass. Frequently, the glass is replaced by chlorite. In another slide, the melt from the gneiss has clearly mingled with the basalt-magma. The zone of mingling is about ¼ inch wide; farthest from the basalt, residual quartz-grains lie in a base originally glassy but now chiefly chlorite and epidote. Nearer the basalt, the glass is filled with felspar-laths in addition to the two decomposition-minerals, and small reaction-rims are seen about the quartz-grains. Nearer still, magnetite and purple augite-grains occur, and the epidote and chlorite are less abundant; gradually this passes into the normal basalt. One would expect that the felspar varies in composition in the different stages, but, unfortunately, a determinative set of readings could not be obtained. The same feature of absorption was seen where there was no glass present. In one slide, one may follow, for the space of about a centimetre, a vein projecting from the basalt into the gneiss, becoming poorer in coloured constituents as it goes; in another, veins of finely crystallised rock, scarcely a millimetre in width, traversing alkali-felspar grains in the gneiss, have abundant finely divided magnetite in the centre, but are free from it at the sides. In such veins, the felspar-laths make a felt

* "The Volcanic Necks of Hornsby and Dundas." Proc. Roy. Soc. N. S. Wales, 1910, p.542.

like that of some trachytes, and augite occurs in broad spongy plates of considerable size.

Finally, there is one instance of the partial recrystallation of an orthoclase-grain in the gneiss to a variolitic mass of felspar-laths. This change occurs at isolated spots in our rock, but among the inclusions of granite in the basalts of the Auvergne, Prof. Lacroix* has found a rock in which the felspar is entirely changed in this manner.

Some features recall the observations of Heineck on the melting down and mingling of granite with basalt-lava in Bohemia, but the process in our rocks is not nearly so far advanced as in the Bohemian†.

### iii. *Granitic Inclusions in the Volcanic Necks of Dundas and Norton's Basin.*

In my account of the inclusions in the volcanic neck at Dundas, there is no mention of granite. Shortly before the quarrying operations ceased there, Mr. Aurousseau obtained a granite-inclusion, which he has handed to me for description. It differs from the majority of the xenoliths in being merely accidental not cognate with the including basaltic rock. It resembles the Gerringong inclusions discussed above. It has suffered considerable pressure, the quartz is greatly strained, and there is some peripheral crushing of the felspar-grains. These consist of large orthoclases, and smaller less irregularly shaped oligoclases. A little decomposed biotite is present. The whole rock has a dirty appearance, and is clouded with dust, kaolin, sericite, magnetite, and a considerable amount of carbonate.

A granitic inclusion has been found in the volcanic neck at Norton's Basin, on the Nepean River, above Penrith. It also is greatly shattered and full of carbonate veins. The structure appears to be crystalloblastic, rather than a normally aplitic one; though this

* Les Enclaves des Roches volcaniques, p 64.

† Geologische-petrographische Verhältnisse der Umgegend von Rothau im böhmische Erzgebirge. Neu. Jahrb. für Min. Beil., Band xxiii., pp. 475-527.

is not definitely marked. The component minerals are orthoclase and quartz, and do not show much strain-effect. This rock may belong to the same ancient series as the inclusions in the Gerringong dyke.

iv. *Bowlingite at Dundas and elsewhere.*

Considerable difficulty was experienced, in the study of the Dundas inclusions, in the determination of the decomposition-products of olivine. The most common material is a green felted mass of very fine fibres, and this was doubtfully referred to pilite, actinolite, anthophyllite and talc*.

In examining, in Paris, Prof. Lacroix' collection of slides illustrative of his work "La Mineralogie de la France et ses Colonies," it was found that the bowlingite of that collection was identical with the decomposition-product in the Dundas rocks, which also, is the usual product of olivine in all the basalts in the Sydney district. The mineral is a hydrous silicate of iron, magnesia, and a varying amount of alumina. Prof. Lacroix thinks it is probably identical with the platy mineral, iddingsite; but the name bowlingite should have priority. It is distinguished by its strong pleochroism, and birefringence, combined with a straight extinction.

* Proc. Roy. Soc. N. S. Wales, 1910, p. 509.

[*From the Proceedings of the Linnean Society of New South Wales, 1915, Vol. xl, Part 1, May 26th.*]

# THE GEOLOGY AND PETROLOGY OF THE GREAT SERPENTINE-BELT OF NEW SOUTH WALES

## Part iv. The Dolerites, Spilites, and Keratophyres of the Nundle District.

By W. N. Benson, B.Sc., B.A., F.G.S., Linnean Macleay Fellow of the Society in Geology.

(Plates xxv.-xxvii., and six text-figs.)

*Introduction.*—The first three Parts of this series recently issued(1) contain some of the results of field-observations made during the years 1909-1911, and of petrological observations made in Cambridge, whither the writer proceeded, having been awarded a Research Scholarship, by the Royal Commissioners of the Exhibition of 1851. Attention was devoted in the field chiefly to the occurrence of serpentine, and the intricate relationships of the dolerites and spilites were less studied, for the peculiar interest attaching to them was then unknown. A perusal of Messrs. Dewey and Flett's paper on British Pillow Lavas(2) showed the importance of these rocks, but the material that had been collected was not sufficient to allow of a detailed discussion, and a re-examination of the field-evidence was necessary. The following is the result of six weeks' further work in the Nundle district, and the study of about one hundred and seventy thin slices of the rocks collected.

In the previous papers it was recognised that the coarse-grained dolerites were intrusive sill-like bodies, and it was believed that the fine-grained, or aphanitic, and frequently amygdaloidal spilitic rocks were lava-flows. At the same time it was remarked that many passage-rocks existed, and that it was frequently found difficult to refer an amygdaloidal dolerite of medium grainsize either to the one group or to the other. The same doubt as to the distinction of flow from sill has arisen in most localities in which these rocks occur. A second difficulty

exists in the nomenclature. It was pointed out that the term "spilite" by original definition and present-day usage covered only such rocks as had undergone a considerable amount of alteration, with the formation of abundant secondary minerals. This has not always been the case among our rocks in New South Wales, unless we are to consider the acid felspar as a secondary mineral (a point which is discussed below), though in all essential features, chemical composition, structural characteristics, and geological association, they agree entirely with the rocks to which Dr. Flett has applied the term "spilite." To indicate this similarity in essential features, it seemed best to extend the use of the term to cover the apparently unaltered rocks in New South Wales, and the name "spilite" will be employed in the sequel in the same sense as before. The distinction adopted to separate the dolerites and spilites, is one of texture and grainsize: the former have a coarse or medium grainsize, with an ophitic, granular, or intersertal texture; the latter are fine-grained, or partially glassy, with a more or less variolitic texture. All gradations may be found between them. Mineralogically, they differ from normal dolerites and basalts chiefly in the strongly sodic nature of their felspars.

*Geological Occurrence.*—The general sequence of sedimentation in the Nundle district has been already discussed in Part ii. of this series. Briefly, the Devonian formation consists of a lower portion, the Woolomin Series, comprising phyllites, tuffs, and radiolarian jasper; a middle portion, the Bowling Alley or Tamworth Series, consisting of radiolarian cherts and claystones, volcanic tuffs and breccias, and coral limestones; and an upper portion, the Nundle or Barraba Series, made up of mudstones, containing *Lepidodendron australe* and radiolaria, with numerous bands of tuff and breccia. Spilites and dolerites occur in some amount in the Woolomin Series, are abundant in the Bowling Alley Series, but are absent from the Nundle Series In Carboniferous times, the formation was strongly folded, and slightly overturned towards the west, and a great mass of peridotite was injected into the plane separating the Woolomin Series from the main bulk of the Bowling Alley Series. A large amount of

strike-faulting took place, which has greatly disturbed the stratigraphical succession, and this revision of the area makes it appear probable that some modification will have to be made in the detailed succession previously announced. It is hoped to discuss this in a later communication, after comparative work has been done in less complex areas. The consideration of the tuffs and breccias (which, doubtless, are cognate with the dolerites and spilites) is also reserved for future study.

Detailed examination of the lines of contact between the igneous and sedimentary rocks, shows that the extent of true lava-flows has been overestimated. In nearly every instance, the igneous rock is intrusive into the sedimentary rock, whether it be a coarse-grained dolerite or a fine-grained spilite: indeed, there has only one instance been observed where doubt can exist on this point. An interesting fact brought to light in this revision, is the frequent occurrence of the pillow or ellipsoidal structure, which is so common a feature of British and German spilite-lavas. But, though it has been held by some writers that this structure is characteristic of lavas that have flowed over the surface of the sea-bottom, it does not appear to be confined to these. Pillow-structure is well developed in the Nundle district in rocks which show intrusive contacts with the surrounding sediments (radiolarian claystones), and the alternative view held by other writers, *e.g.*, Teall(3) and Geikie(4)* that pillow-structure may also be produced in lavas intrusive into loosely compacted clays on the sea-floor, is the one most applicable to the features seen in the Nundle district. The various explanations that have been offered for the explanation of pillow-structure have been discussed by Clements(5), Daly(6), Sundius(7), Van Hise and Leith(37), whose papers give extensive bibliographies of the subject.† Tempest Anderson describes the formation of pillow-structure in recent

* "Basic lavas flowing into water or watery silt."

† Since the above was written, Wilson's discussion of the origin of pillow-structure in the Archæan rocks of North-western Ontario has come to hand (The Geology of the Kewagama Lake Map-Area, Quebec. Geol. Survey of Canada. Memoir 39, p.50). He cites, though he disputes, Lawson's statement that the ellipsoidal rocks of California are intrusive (Mining and Scientific Press, No.119, Vol. iv., 1912, p.199).

lavas in Savaii as follows(8): —"An ovoid mass of lava still in communication with the source of supply, and having its surface, though still red-hot, reduced to a pasty condition, would be seen to swell or crack into a sort of bud with a narrow neck like a prickly pear on a cactus, and this would rapidly increase in heat, mobility, and size, till it either became a lobe as large as a sack or pillow, like the others, or perhaps stopped short at the size of an Indian club or large Florence flask. Sometimes the neck supplying the new lobe would be several feet long and as thick as a man's arm before it would expand into a full-sized lobe; more commonly it would be short, so that the fresh-formed lobes were heaped together." Sundius accepts this as the process by which the pillow-lavas were made in the pre-Cambrian rocks of Lappland, but suggests that the pressure of the moving lava may break off and separate the pillows from one another: this would account for the rarity of connecting tubes between the pillows in the lavas he describes. Daly, in his recent work(9), compares the production of these lava-ellipsoids to the formation of the "spheroidal state" in water. Sundius notes that the effect must depend on the possession by the magma of a definite degree of viscosity, and finds in this the explanation of the association of pillowy and non-pillowy lavas. Mr. Harker has pointed out(10) that there is only a slight difference between the conditions of injection of lava into the loose muds of sea-floor, and an outflow of lava over the sea-floor, which is but the injection of magma between the soft muds and the overlying water.* The difference is naturally to be found in the slower cooling of the lava in the former case owing to the blanketing action of the muds. It seems quite probable that a flow with typically pillowy surface may show an intrusive contact with the mud-surface on which it rests, and such may be the case in parts of the Nundle district. While, in many instances, pillow-structure is a feature of deep-sea marine flows, as is shown by the fine-grained nature of the sediments with which they are associated, it is clear, from Tempest Anderson's observations, that it cannot be confined to such situa-

* Compare F. von Wolff. Der Vulkanismus (Stuttgart, 1913), pp. 252 and 255.

tions; and, moreover, pillow-lavas have been found associated with lacustrine deposits(36). Jukes-Brown has argued for the shallow-water origin of the radiolarian rocks associated with the pillow-lavas of Ballantrae in Ayrshire(11), and Professor David and Mr. Pittman have declared that the Tamworth radiolarian claystones etc., which are continuous with those associated with the pillow-lavas of the Nundle district, were developed in comparatively shallow water(12).

The mode of occurrence of special masses may now be described. No doubt can exist as to the intrusive character of any of the large patches of dolerite marked on the geological map of the district given in Part ii. They all represent areas of dolerite of coarse or medium grainsize, and almost free from vesicles. Not infrequently there occur in them veins of very coarse-grained dolerite-pegmatite. Their intrusive contacts with the surrounding sediments are clearly observable. Often they have themselves been invaded by later masses of dolerite, which have a strongly marked, fine-grained, chilled, marginal zone against the invaded rock. Such contact-zones may be seen in several places in the lower part of Munro's Creek.

The areas marked as spilite-flows require more detailed consideration. The most important is that crossing the Peel River two miles south of Bowling Alley Point, and extending thence towards Hanging Rock. In the cutting on the main road, it consists of a group of stratiform masses, which may be seen to have intrusive contacts with the radiolarian claystones on either side. The same features are to be seen where this zone crosses Madden's, Moonlight, and Daylight Creeks, south of this point. The individual sills have a medium to fine grainsize, and are often amygdaloidal. In microscopical texture, they vary between ophitic dolerites and variolitic spilites: this variation may be seen on either side of a sill, and is due to marginal cooling: frequently, however, the sill is of uniform texture throughout. Multiple sills occur here and there, with chilled edges between the component parts. The vesicles are filled with calcite, epidote, and chlorite, and along the northern slope of Tom Tiger, axinite is frequently present in the vesicles, while axinite- and quartz

veins occur in the vicinity. Owing to the abundance of porphyry dykes in the vicinity, it was thought probable that the boric acid may have been derived from an underlying mass of granite which approached the surface in this region, though none of the porphyries contain tourmaline. There is, however, the possibility that the axinite may proceed from the dolerite-magma itself: axinitic contact-rocks are occasionally observed about diabases in Germany and New Jersey(13).

On Tom Tiger, the prominent peak north of the junction of Swamp Creek and the Peel River, pillow-structure is to be seen in the crags about the summit. The pillows are sometimes more than a yard in diameter, and their marginal zones of chilling are narrow and not well marked. They are separated by narrow bands of epidote, calcite and quartz. No exposures of the contact-line between the sediments and the igneous rock can be seen on Tom Tiger itself, but in Swamp Creek, half a mile to the south, a strongly intrusive junction is exposed. The bared rocks in the creek-bottom show that a considerable thickness, about ten yards, of fairly coarse-grained spilite is full of irregular, twisted fragments of chert of all sizes. The whole appearance suggests that the igneous rock invaded partially consolidated sediments. Pillow-structure is also observable here. Following the zone further southwards, pillow-structure is again met with on the ridge separating Swamp Creek and Happy Valley, and from this was obtained the specimen of spilite, of which an analysis was given in Part iii. The map in Part ii. shows a break in the spilite-zone south of this point, but it has now been proved to extend uninterruptedly to beyond Oakenville Creek, and the contacts with the sedimentary rocks, wherever visible, show the intrusive nature of the igneous rock.

A thickness of over four hundred feet of pillow-lava is exposed in the bed of Happy Valley. The pillows vary from a few inches to over six feet in diameter; the inner portion is porphyritic, with a subvariolitic base; the outer and rapidly chilled portions are aphanitic, and have frequently a variolitic structure. Vesicles are not abundant, nor are they concentrically arranged; they tend to concentrate towards the centres of the pillows. The

individual masses are separated, as usual, by narrow bands of epidote, etc., and quite large crystals of quartz or epidote may occur in the cuspate cavities between several pillows; no radiolarian chert has been observed in such a situation, though it occurs in this manner in several British localities. Occasionally, the pillow-lavas are invaded by massive non-pillowy dolerite, which sometimes has chilled marginal zones.

Pillow-structure may also be observed on the cuttings on the Hanging Rock road, though greatly obscured by spheroidal weathering. The spilites are here intersected by a dyke of hornblende-lamprophyre. The exposures on Oakenville Creek, just to the south of the road, are almost entirely covered with drift; one exposure, however, shows a most intimate mixture of spilite and chert. Fig.1 was traced from a flat-ground surface of a

Text-fig.1.—Spilite intrusive into radiolarian clay. (Nat. size).

specimen obtained from here. The microscopical character of the entangled chert suggests that, in this case, it is largely, if not entirely, the product of infiltrations subsequent to the consolidation of the igneous rock. Such is believed by Messrs. Reynolds and Gardiner* to be the origin of the strings and patches of chert in the spilites of Kilbride Peninsula, County Mayo, Ireland.

Another important mass of pillowy rock commences nearly a mile further up Swamp Creek than the point where the first zone crossed, and continues thence up the gorge to the falls. It

* Quart. Journ. Geol. Soc., 1912, pp.80-81.

may be a repetition of the first zone, though this does not seem probable at present. Near the entrance to the gorge is exposed the mass of chert and spilite shown in Fig.2A. This is the only instance in which doubt may exist as to the intrusive nature of the pillowy rock. The manner in which the banding in the chert bends in and out sympathetically with the boundaries of the lava-pillows, may indicate that they were deposited on a pillowy surface. On the other hand, the upper mass of lava has transgressive boundaries against the chert. It is not pillowy where it is in contact with the chert, but the structure becomes observable about thirty feet above the chert. The upper mass may be a surface-flow which has broken up the lines of bedding of the clays over which it flowed, but the section does not preclude the possibility that both the upper and lower masses of igneous rock were intrusive into soft clays, crumpling, or breaking through their lines of bedding as they went. Exposures of chert and spilite observed higher up the gorge clearly exemplify the second alternative. Indeed, there does not seem any other explanation possible for the features illustrated in Figs.2B and 2C These narrow bands of chert lie in a great thickness of pillow-lava, probably four or five hundred feet (screes and tangling brushwood prevent more exact measurement). The pillows may be as much as eight feet in diameter, and are just like those occurring in Happy Valley. Not infrequently they are quite free from vesicles In between the pillows is often a very fine-grained rock which looks like chert, but which the microscope proves to be made up of quartz, epidote and a little actinolite; the same minerals, less finely crystallised, form the usual bands separating the pillows. As in Happy Valley, there is no radiolarian chert between the pillows, nor do they show the strongly marked radial contraction-cracks that are sometimes seen in similar rocks in other parts of the world. There are associated massive intrusive dolerites quite indistinguishable, in hand-specimen, from the rock in the centre of the pillows (though under the microscope they may appear less variolitic), and it is often difficult to determine whether there is a passage from the pillowy rock into the massive dolerite, or whether there is a definite boundary between them.

No very definite statement is possible with regard to the other masses of spilite mapped, since their boundaries are rarely observable. It seems safest to consider them, also, as intrusive, whether they are vesicular or not, when there is no evidence to the contrary, and particularly when the rock is not pillowy, and

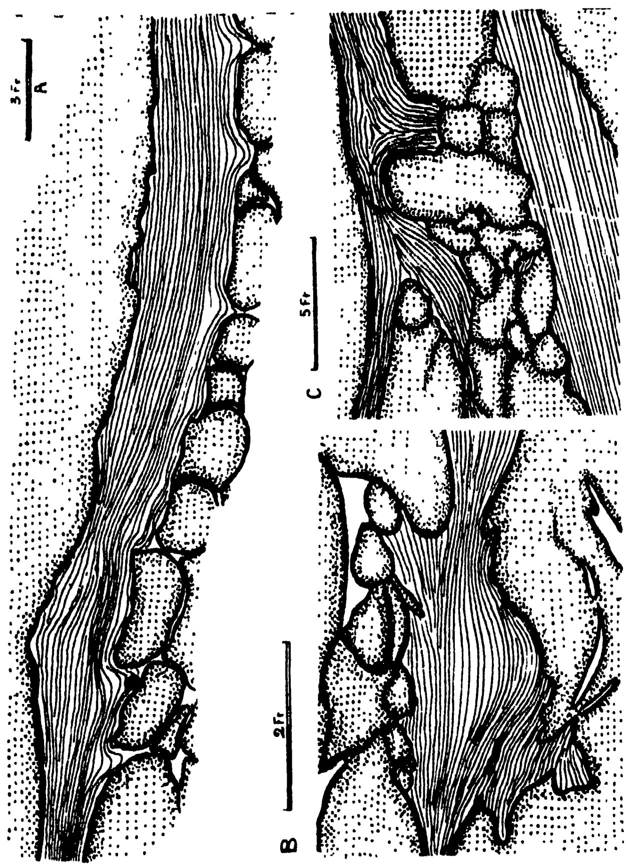



fig.2.—A and Swamp Cre Gorge.

the texture is not more than subvariolitic. Even highly variolitic rocks have been proved to be intrusive. On such negative evidence, we may class as intrusive spilites or amygdaloidal dolerites, the bands shown on Moonlight Hill, those on the western side

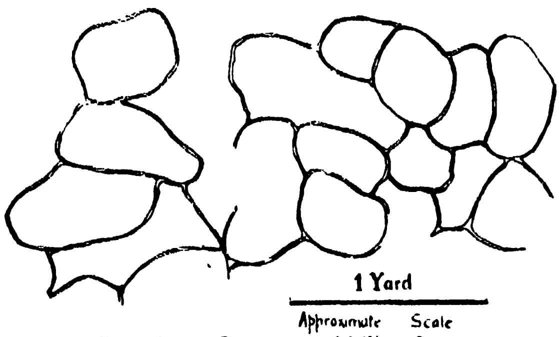
of Tom Tiger, and those forming the White Rocks overlooking Munro's Creek (see Part ii., Plate xxiii.). Confirmation of the intrusive nature of the first-mentioned group of spilites, is afforded by two poorly exposed contacts, and in the last case we find, on tracing the horizon of the igneous from the crags down across the scree-covered slopes into Munro's Creek, the great mass of White Rock is represented by a number of narrow sills, all intrusive into the cherts or claystones. But, though the sills often show transgressive boundaries, the general course of the mass is parallel to the strike of the country.

With regard to the statement made previously, that a lava-flow occurred on Moonlight Hill, swamping the coral-limestone, some modification must be made. A closer examination of the field-occurrence showed that the specimen described was not part of a flow, but of a mass of agglomerate, composed almost entirely of spilite-fragments, and evidently formed adjacent to the point of eruption. As stated, it contains large and small masses and fragments of limestone, some of which contain recognisable fossils of coral. On the western side of Munro's Creek, however, opposite to the Razorback, there is also an association of spilite and limestone, with somewhat analogous characters. The limestone, unfortunately, is so crystalline that no organic remains are preserved. It forms a lens about seventy yards long and ten wide. At its northern extremity, it is most intimately mixed up with lava showing skeleton-crystals and other indications of rapid chilling, and this passes laterally into a solid mass of lava, containing numerous fragments of limestones and calcite-filled vesicles. The igneous rock must here be an intrusive body, formed probably at a small depth below the sea-floor.

The nature of the spilite-occurrences in the Woolomin Series is not clear. Dolerites have been proved to occur, and a special type of spilite as yet not chemically analysed. They are rather crushed, and are less variable in texture than the igneous rocks in the Middle Devonian. Only one instance of pillow-structure (and that a dubious one) has been seen in the spilites of the Woolomin Series in the Nundle district; it occurs in a tributary of Munro's Creek. Generally the rocks are quite massive, and free from

vesicles. It may be mentioned here that well marked pillow-structure has been observed in some amygdaloidal spilites occurring in the Woolomin Series in Portion 56, Parish of Loomberah, by the bridge over the Peel River, eleven miles south of Tamworth. These rocks are highly altered, as much so as the majority of the British spilites known to the writer. It cannot be doubted that long strips of Bowling Alley (Middle Devonian) rocks are faulted or folded in among the Woolomin Series, but the spilites of these strips should be usually distinguishable from those belonging to the Woolomin Series. Distinction between the two sets of dolerites is not clear at present.

Other rock-types occur that are cognate with the spilites, though differing from them in varying degree. In Munro's Creek, commencing at the Razorback, and running thence up to the end of




Text-fig. 3.—Pavement of Pillow-Lava.

the westernmost branch of it, is a series of pale grey green rocks. This mass was overlooked in the first survey, being thought to have been merely a rather altered tuff. Its eastern side adjacent to the serpentine is a flow-breccia, and traces of the same rock appear on the western side of the mass on the other side of the creek. The main mass is composed partly of a very fine-grained variolite with a most peculiar microscopical structure, partly of a subvariolitic porphyritic rock, and partly of a rock with an almost doleritic texture, intrusive into the finely granular or aphanitic variolitic rock. The porphyritic rock has a well developed pillow-structure, and several pavements of it are exposed in the bed of the creek. Fig. 3 illustrates one of these.

The doleritic type is abundant, but does not exhibit pillow-structure. It has not been possible to determine the mode of occurrence of these rocks. They lie in the most disturbed zone in the Bowling Alley rocks, and the steep scree-covered slopes on either side do not expose any lines of contact between the sediments and the igneous rocks. It is almost certain that the series is faulted and folded, probably in a syncline. The occurrence of the breccia on both sides of the creek may be due to this; lines of shearing are to be seen in the rock. It is not clear, also, whether any of the rocks were actual flows. At the southern extremity of the mass there is a band of variolite only a yard thick, lying in a rather wider band of decomposed flow-breccia. The line of contact between this and the sediments is indecisive. There is also no clear evidence as to the relation between the variolitic leucocratic rocks and the strongly magnetitic spilite, described above as intrusive into a limestone. There seems to be almost a passage between the two types. In the creek below, pillowy spilitic boulders are associated with the variolites, and here again passage-rocks seem to occur, but the relation of the two types *in situ* is unfortunately obscured. A passage from a rock free from magnetite into one rich in that mineral is not impossible, as will appear from the consideration of the magnetite-keratophyres. A dyke of odinite traverses the series.

The most remarkable of all the rocks are the keratophyres. Of these are to be distinguished the keratophyres proper, the magnetite-keratophyres, the quartz-magnetite-keratophyres, and the quartz-keratophyres. The simplest occurrence is that of the keratophyre at Hanging Rock, which has been mentioned previously (Part ii., p.586; Part iii., p.666). It is also in a zone of great disturbance, and its relations are obscured. It seems preferable to consider it as a short sill, rather than as a volcanic plug. The rock is made up almost entirely of plagioclase, and analysis shows its extremely sodic character.

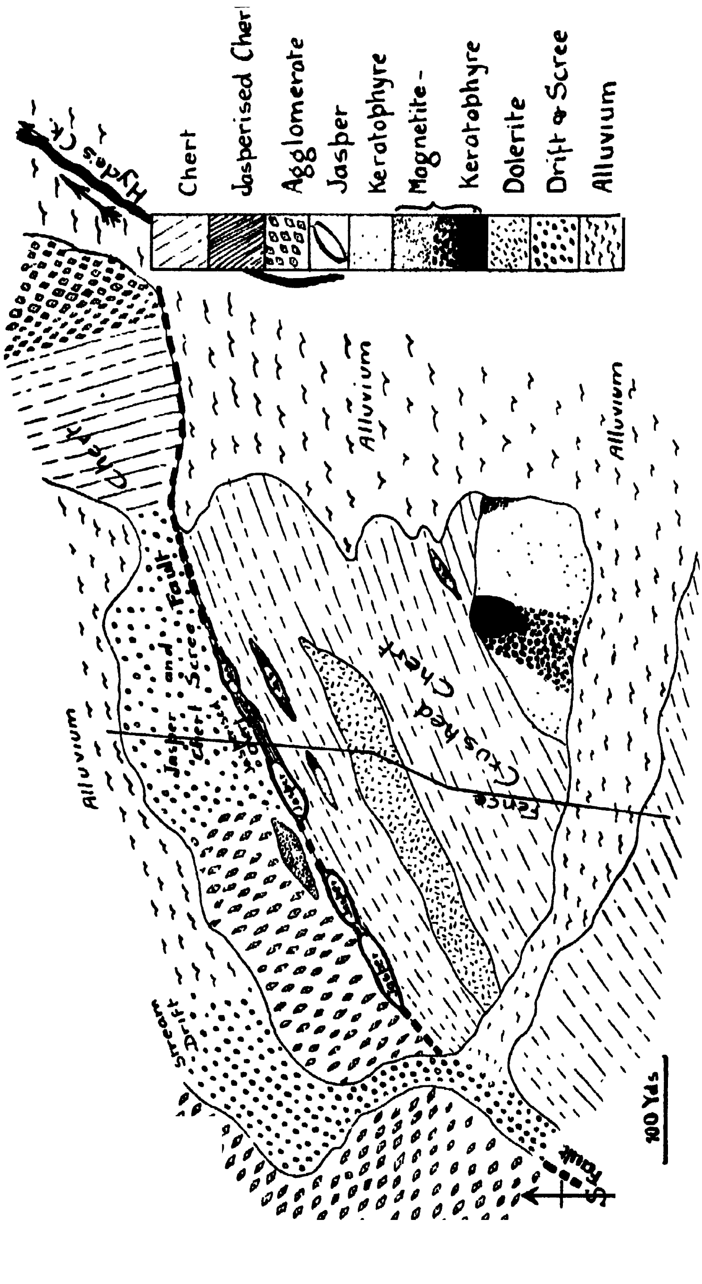
The magnetite-keratophyres are linked by passage-rocks both to the spilites and to the keratophyres. In the one sequence, the spilite passes into magnetite-keratophyre by the gradual diminution in the amount of augite present, and the increase in

amount and decrease in grainsize of the magnetite; and by the substitution of a very slaggy for an amygdaloidal habit. The change from keratophyre into magnetite keratophyre is a more complex one, and is discussed at length in the sequel.

North and south of Folly Creek, near the serpentine, there are small masses of spilitic magnetite-keratophyre, which seem to be intrusive into the adjacent sediments. No unusual tectonic features appear in their neighbourhood. Here and there throughout the district are little patches of spilite, richer than usual in magnetite, and showing some approach to the character of magnetite-keratophyres. These, however, are of rare and limited occurrence only.

The main region of development of the purely keratophyric type of rocks lies north-west of Bowling Alley Point in the region between Hyde's and Cope's Creeks. About a mile due west of the small infaulted area of Permo-Carboniferous rocks, is what may be termed the Hyde's Creek Complex. It forms a small ridge, running back from the creek. Fig.4 is a map of the occurrence. The normal strike of the region is that seen to the north-east of the figure, namely, N.N.W.-S.S.E. The strata following this strike are steeply inclined cherts and agglomerates or breccias. The strike warps round from N.N.W. to W.N.W. A fault cuts almost perpendicularly across this, and south of the fault lies an area, the strike of which swings from N.E. to E.N.E. The line of fault is marked by a series of masses of jasper, not of the usual red homogeneous character, but more clearly a secondary vein-like and vesicular rock, with quartz and chalcedony and crystalline hæmatite; the last is present as a finely divided colouring matter, as crystals in druses, and in veinlets through brecciated jasper. Where the jaspers cease, there continue zones of red jasperised radiolarian chert. Microscopical sections of these clearly show the metasomatic effect of ferruginous siliceous solutions.

Intrusions of igneous rock occur both north and south of the fault-line. At the southern end of the hillock is a complex of keratophyre and magnetite-keratophyre as shown. No actual contact with the chert has been seen, but the intrusive nature of



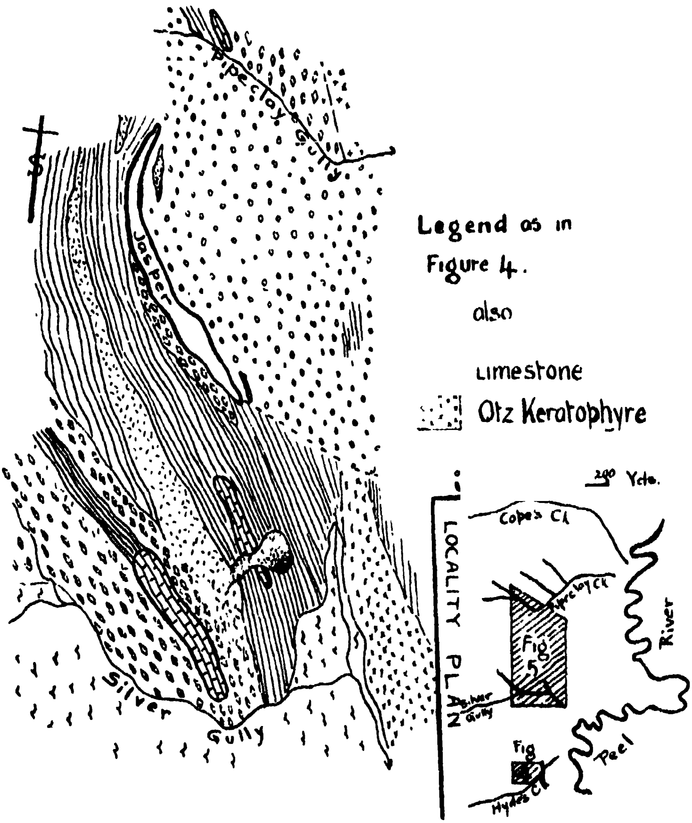

Tex Hyde's C mp.

the igneous rock can scarcely be doubted. The keratophyre, when fresh, has a translucent white colour, and is divided up into small portions, generally about two millimetres in diameter, closely compacted together, and generally without any intervening matrix. A little pyrites is usually present. On weathering, a white kaolinitic rock is produced, or a red or yellow ochreous one. Towards the centre of the mass, and also to the north-east, magnetite-keratophyre is developed. The passage from the one rock into the other is a gradual one through many peculiar intermediate types to be subsequently described. The increasing amount of magnetite may be regularly distributed, giving a uniform grey rock, but more usually it is very irregular, producing breccia-like or nodular rocks. Following these, are almost pure magnetite-keratophyres with but few veinlets of felspathic rock. Finally, in the centre of the ferruginous area, is a black, heavy, and very slaggy magnetite-keratophyre, in which the abundant irregular vesicles are never amygdaloidal, and are nsually filled with calcite. A similar passage from purely felspathic into richly magnetitic rock occurs on the summit of the hillock. Between this and the former mass, is a long intrusion of quartz-dolerite, containing very little augite, and passing, on the margin, into fine-grained, non-porphyritic rock, the composition of which approaches that of an augitic quartz-keratophyre. North of the jasper-band, is a lenticular patch of very vesicular red-brown quartz-magnetite-keratophyre. The vesicles are round or slightly amygdaloidal, and the rock is not at all slaggy.

Along the zone of agglomerate to the north, other small occurrences of quartz-magnetite-keratophyre may be found, and the line of contact between these and the agglomerate is very difficult to define.

At Silver Gully, a mile north of the Hyde's Creek complex, is a second complex, of which a sketch-map is given (Fig.5). This is only very roughly drawn to scale. Beside the agglomerate, is a band of limestone forming a bold outcrop. To the east of this is a narrow band of spilitic agglomerate, beyond which is a long intruion of dolerite like that in the Hyde's Creek complex. There

does not seem to be a clear boundary between the agglomerate and the dolerite, and there is certainly no boundary between the dolerite and an offshoot of spilitic magnetite-keratophyre, which cuts across a second band of limestone, and opens out into a roughly circular area of fine-grained, red-brown and highly




Text-fig. 5.—Silver Gully Complex.

vesicular (not slaggy), not very ferruginous magnetite-keratophyre, which passes into a richly magnetitic slaggy rock. The dolerite-sill may be traced for about half a mile to the north, and the agglomerate at its western edge seems to grade into a coarsely granular porphyritic quartz-keratophyre, which, on micro-

scopic examination, proves to be composed entirely of fragmental quartz and albite. Agglomeratic rocks of a rather different nature, composed of fragments of keratophyre, magnetite-keratophyre, and dolerite in a matrix of keratophyre, lie to the west of a great band of jasper, which forms the ridge of the hill between Silver Gully and Pipeclay Creek. This agglomeratic rock appears to be rather of the nature of an intrusive igneous rock, filled with cognate inclusions.

The jasper has the same peculiar feature as that of the Hyde's Creek complex. The scree from the ridge covers the easterly slope, and through it there appear two small areas of vesicular quartz-magnetite-keratophyre like that north of jasper at Hyde's Creek.

Below the limestone on Pipeclay Creek, there is another intimate association of agglomerate and massive igneous rock (in this instance a porphyrite) in which it is difficult to distinguish between an agglomerate, and an igneous intrusion filled with inclusions. This has not been investigated yet. East of this mass, and extending from Silver Gully, across Pipeclay Creek towards Cope's Creek, is a band of very siliceous keratophyre. It is a grey rock, often containing small felspar-phenocrysts, very vesicular, and often amygdaloidal. The long amygdules are filled with calcite, or frequently with quartz or agate, while the microscopic features of the rock show further signs of the action of silicifying solutions. Occasionally the rock is traversed by veins of red jasper. In this case, also, there is no line of contact with the sediments exposed, nor is it obvious that the mass is an intrusion. It is very uniform in character, has a width of from fifty to a hundred yards, and is not associated with any obviously ejectmental deposits.

### Petrographical Characters.

In the foregoing, the Devonian igneous rocks were classed into the dolerite-spilite series, the keratophyres, quartz-keratophyres, magnetite-keratophyres, and the variolites of Munro's Creek. They were briefly described in Part iii. of this series, but a more detailed account is now possible, and some modification of the former statements must be made.

## 1. *The Albite-dolerite and Spilite Group.*

*General features.* - These rocks are by far the most abundant of the Devonian igneous suite. Mineralogically and chemically, they form a very well marked homogeneous group; and, though the variety of textures developed is very great, they are connected with one another by a complete series of intermediate textures. At the acid extremity of the group there are passage-rocks into the keratophyres. The mineral composition is simple. Throughout the whole group, the predominant mineral is an acid plagioclase. Augite occurs in amount varying from one-fifth to more than one-half of the amount of the felspar. Ilmenite or titaniferous magnetite is next in order of abundance, but varies within wide limits, as does also the amount of apatite. Quartz varies greatly in amount, and in the rôle that it plays: it may occur in isolated grains, in interstitial mosaic, or in micro-pegmatitic intergrowth with felspar. Rarely a small amount of primary, brown hornblende is present. Pyrites is usually present, though only to a small extent. No definite sign of olivine is seen, even among the decomposition-products. Potassic minerals, such as biotite and orthoclase, are absent. The feature which distinguishes the whole group from rocks, similar in chemical composition and geological association in other parts of the world, is the comparative freedom from decomposition. Secondary minerals are present in most of the rocks, calcite, chlorite, or epidote, but usually only in small amount. Complete uralitisation is almost confined to the dynamically altered rocks of the Woolomin Series.

*Chemical composition.*—The chemical composition of this series is exemplified by the table herewith, and may be contrasted with the average composition of basalts as given by Daly(9). The chief feature of our rocks is their richness in soda, and, to a lesser extent, in titanium, (Daly points out that the two often go together) while the alumina, potash, and lime are low. The total iron oxides and magnesia, and the silica of the rocks free from quartz, are about the same as that of the average normal dolerite.

TABLE OF ANALYSES OF ROCKS OF THE NUNDLE DISTRICT.

| | 117 | 1002 | 1021 | 145 | 1109 | 1013 | 1086 | 1107 | 53 |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ ... | 48·22 | 48·35 | 51·19 | 54·88 | 48·61 | 60·39 | 56 95 | 48 04 | 49·06 |
| $Al_2O_3$ .. | 14·82 | 14·12 | 14·40 | 12·62 | 18·54 | 18·40 | 17·87 | 14·47 | 15·70 |
| $Fe_2O_3$ ... | 0·56 | 4 87 | 4·43 | 3·02 | 0·34 | 1·03 | 4·49 | 0·87 | 5·38 |
| FeO .. | 9·25 | 10·27 | 9·04 | 7·11 | 6 79 | 3 50 | 6 00 | 11·87 | 6·37 |
| MgO ... | 5·58 | 4·78 | 4·51 | 3·73 | 7·22 | 1·27 | 0 98 | 5·56 | 6·17 |
| CaO .. | 8·81 | 6·71 | 6·05 | 4·16 | 10 20 | 1 53 | 2·30 | 9·11 | 8 95 |
| $Na_2O$ ... | 4 95 | 4 63 | 4·18 | 6 01 | 4·13 | 8·79 | 8·80 | 4·06 | 3·11 |
| $K_2O$ . | 0·44 | 0·38 | 0·78 | 1·10 | 0·18 | 0·46 | 0·38 | 0·64 | 1·52 |
| $H_2O$ + . | 2·54 | 2·00 | 1·82 | 1·76 | 2 02 | 1·37 | 0·71 | 2·15 | 1·62 |
| $H_2O$ – .. | 0·15 | 0·30 | 0.24 | 0·23 | 0·20 | 0·20 | 0 38 | 0·13 | |
| $CO_2$ ... | 1·40 | abs. | abs. | tr. | 1·19 | 1·70 | 0·91 | 0·26 | — |
| $TiO_2$ ... | 2 68 | 2 84 | 2·69 | 3·63 | 0 90 | 0·80 | 0·89 | 1·97 | 1·36 |
| $P_2O_5$ .. | 0·23 | 0 35 | 0·40 | 0·44 | tr. | 0·12 | tr. | 0 08 | 0·45 |
| $FeS_2$ ... | 0·37 | 0·22 | 0·19 | 0·71 | 0 04 | 0·02 | 0·04 | tr. | — |
| NiO . | 0·03 | — | — | 0·05 | — | — | — | — | — |
| MnO ... | 0·23 | 0·18 | 0·21 | 0·25 | 0·08 | 0·08 | 0·08 | 0·21 | 0·31 |
| BaO .. | abs. | 0 10 | abs. | abs. | — | abs. | — | — | — |
| | 100·26 | 100 10 | 100·13 | 99·70 | 100·44 | 99·66 | 100·73 | 99 42 | 100 00 |

117. Spilite, Frenchman's Spur, Nundle. (See Part iii., p.704, N.T.415).
1002. Dolerite, Munro's Creek, Bowling Alley Point.
1021. Quartz-dolerite, Munro's Creek.
145. Quartz-dolerite, Hanging Rock. (Part iii., p.704, N.T.237).
1109. Variolite, Munro's Creek.
1013. Keratophyre, Hanging Rock, Nundle.
1086. Magnetite-keratophyre, Hyde's Creek.
1107. Dolerite in Serpentine, Chrome Hill, Bowling Alley Point.
53. Average composition of all basalts. (Daly, "Igneous Rocks and their Origin," p.27).

*Mineralogical composition.*—The high percentage of soda is expressed in the very acid nature of the plagioclase developed. If we calculate the composition of the felspar, assuming that all the orthoclase plays the rôle of albite in the plagioclase, we have the following table:—

No. 117. Felspar Molecules... $Or_4Ab_{50}An_{30}$ or $Ab_{74}An_{26}$
No. 1002. Felspar Molecules... $Or_4Ab_{74}An_{30}$ or $Ab_{72}An_{28}$
No. 1021. Felspar Molecules... $Or_9Ab_{68}An_{33}$ or $Ab_{73}An_{27}$
No. 145. Felspar Molecules... $Or_{12}Ab_{97}An_{15}$ or $Ab_{88}An_{12}$

Thus all the felspars, with the exception of the last, are oligoclase-andesine; the last is albite. Optical tests, however, show

that all the felspar in the rocks is albite or acid oligoclase. The excess of anorthite molecule must be present in the pyroxene, which is abundant in the first three, but rarer in the last: the presence of some epidote and chlorite also removes some of the alumina that is reckoned in the calculation as if it formed anorthite. The felspars are often quite clear, and their position in the acid group is nearly always determinable from their positive biaxial character, and their refractive index which is lower than that of Canada balsam. More exact determinations are difficult. The Carlsbad twinning law has not been seen in combination with the albite law; extinction-angles measured on the albite lamellæ perpendicular to (010) give maxima between 8° and 16°, indicating a composition between acid oligoclase and albite. Prof. Becke's methods of investigation in convergent light are rarely applicable(14). A measurement made of the angle between the points of emergence of the optic axes of adjacent lamellæ of a pericline twin, indicates a composition of about $Ab_{85}An_{15}$, which again is within the limits expected. Occasionally, the felspars are slightly zoned, albite is at the margin, and oligoclase within. In the earlier account of these rocks, it was stated that andesine predominated among the quartz-dolerites. This is not confirmed by a more extended investigation. Andesine occurs but rarely, and the crystals of which it forms the central parts are strongly zoned. The determination of andesine in some slides remains doubtful owing to the dusty character of the felspar, and in other cases a testing of the Canada balsam shows that it has been insufficiently cooked, and has therefore a refractive index less than that of albite, leading to the above-mentioned error. It was reported, also, that spongy felspar occurred in one instance, though the mineral is usually compact; further search has not brought to light any other instance of spongy felspar than one described. In the porphyritic rocks, no difference can be found between the composition of the microlites and of the phenocrysts. Apart from its unusual composition, there is little to suggest that the acid felspar is not of primary origin. In one rock only has labradorite been found, namely, 1040, the specimen illustrated in Fig. 1. The felspar forms clear fresh laths, and is associated

with fresh augite, and chloritic decomposition-products of a glassy base.

The pyroxene, also, is generally fresh. Though in many cases there has been a small amount of chlorite, uralite, epidote, and calcite produced from the pyroxene, there is nothing that resembles the highly altered state of pyroxenes in most British spilites. No alkaline pyroxenes have been observed, nor any rhombic pyroxene. Dr. Cox suggests that the quartz-dolerite of the spilitic series in Wales(15) may be found to contain augite rich in the rhombic pyroxene molecule. The present series of rocks have been specially searched for this feature, and the optic axial angle of many crystals was measured by the graphical methods of Professor Becke. They proved to be very uniform in character; the value of 2V lay in nearly all cases between 42° and 48°. This is rather less than the normal value for augite, but does not prove the presence of enstatite-augite, in which the angle may diminish to zero. Calculation from the analyses shows, however, that some of the $RSiO_3$ molecule must be joined with diopside molecule in the pyroxene developed. There is no difference between the character of the pyroxene in a quartz dolerite and that of a dolerite free from quartz. Sahlite-structure is never seen, though twinning is often present. The pyroxene is generally greyish-green in colour when seen in section, and in some of the more finely granular rocks it has a purplish tinge.

The hornblende has the usual reddish-brown colour of hornblende in basic rocks, is rarely present, and in small quantities only.

The ilmenite occurs in plates of very irregular size and shape, and, in more altered rocks, is frequently leucoxenised. The apatite and pyrites are as usual; the mode of occurrence of the quartz will be described below.

*The Texture.*—The distinction between the dolerites and spilites is one of grainsize only, and is a most indefinite one. There is a wide range of texture between which every gradation can be found. At the holocrystalline end of the series, the most marked type of texture is that of the intersertal quartz-albite-dolerites of Hanging Rock. In these, the crystallisation of the apatite

occurred first, that of the ilmenite and augite followed; large prisms of plagioclase then formed, often with quite idiomorphic extremities; their outer portions are clear albite or oligoclase; the inner parts are often dusty and indeterminate; though generally acid, they appear at times to have a core of andesine. The mesostasis between these crystals is very varied in character: sometimes it is merely a quartz-mosaic of minute grains; or it may be a mosaic of minute grains of quartz and an untwinned felspar, which has the same refractive index as that composing the outer zones of the plagioclase crystals; or it may be a micro-pegmatitic intergrowth of quartz and felspar, radiating from the edges and particularly from the coigns of the large felspar crystals, and these micropegmatitic fringes may be narrow or may stretch across the whole space between the enclosing crystals. Again, the mesostasis may consist of a pericline-twinned mass of felspar, wrapping round the end of the plagio-clase prisms that project into the interstitial spaces. Finally, there are instances of the whole interstitial space being occupied by a few large quartz-grains; this last type of mesostasis, though fairly common in the dolerites directly associated with the spilites, is absent from a purely doleritic mass like that of Hanging Rock. Apatite crystals are rarer in the mesostasis than in the main part of the rock; this is the reverse of a feature commonly observed in the quartz-dolerites(**16**).

With decrease in the quantity of quartz, the rock-texture becomes conditioned more entirely by the position of the felspar prismoids. In Munro's Creek, some of the dolerites have a strongly gneissic texture, owing to the parallel position of the felspars. Augite is generally fairly abundant, forming about a third of the rock; it is usually roughly idiomorphic. Ilmenite and apatite vary greatly in amount.

From this stage there is a passage into the ophitic texture, with a decrease in the size of the pyroxene crystals. Rocks with this texture are not so common as the former, and are among the purely doleritic sills, but the structure is most developed in connection with the passage-rocks between the dolerites and spilites (see Plate xxv., fig.2).

The majority of the rocks which we shall term spilites have the texture characteristic of the spilites of Germany, and differ from these only in their greater freshness. They are partially porphyritic or glomeroporphyritic. The glomeroporphyritic types have small ophitic aggregates of augite, felspar, and ilmenite, as well as isolated phenocrysts of the same minerals. The groundmass varies considerably; in some rocks it has a basaltic habit, but differs from basalt in the following peculiarity: the felspar phenocrysts have been enlarged, their outline is no longer sharp and rectilinear, but embayed, each embayment being filled with a grain of augite, on either side of which there project little tongue-like points of felspar (see Plate xxv., fig.3). Somewhat similar characters have been described by Rinne from the diabases of the Harz Mountains(17). There is usually no flow-arrangement of the felspars, and, though the rocks are vesicular in places, there is no special alteration in texture noticeable about the vesicles.

Another type of groundmass has much greater distinction between base and phenocryst, and a more marked flow-structure. This is very characteristic of the zone of spilitic rocks that extends north and south from Tom Tiger. The sharply bounded plagioclase phenocrysts have frequently microlitic extensions, giving swallow-tailed, or pronged terminations. The augite phenocrysts are moulded against the felspars, and do not show skeletal forms. Ilmenite and magnetite form long irregular aggregates of small grains. The groundmass consists of felspar, in the form of strips not much shorter than the phenocryst, and varying in size thence down to the finest microlitic dimensions. Its outline is rarely rectilinear; it has skeletal extensions, or is bent and twisted, forming shreds rather than laths. There is sometimes a general flow-arrangement; at other times the felspar is more radially grouped (a subvariolitic texture), or is quite irregular (see Plate xxv., fig.5). Associated with the felspars, are minutely granular augites and ilmenites; not infrequently the augite lies in narrow streaks between the felspar shreds. With decreasing grainsize, this texture becomes more and more confused, and the rock is more readily chloritised. Skeleton-

crystals of augite occur, which are like rods made up of very minute grains, and feathered, one might say, with tiny plates of ilmenite. Such minutely granular augite is also frequently around minute laths of plagioclase. In many of these rocks there is more or less brown glass in the base (see Plate xxv., fig.6). The spilites are frequently vesicular, and sometimes, in the holocrystalline spilites, the vesicles are surrounded by hypocrystalline rock. One of the most remarkable types of rock is that in which an ophitic dolerite of medium grainsize has interstitial areas of fine-grained subvariolitic rock (Plate xxv., fig.2).

The amygdaloidal dolerite and holocrystalline spilites described above are characteristic of the non-pillowy masses of spilite and the central portions of the pillowy spilites all along the Frenchman's Spur, and the slopes north of Tom Tiger. The outer portions differ in being hypocrystalline. The phenocrysts and felspar microlites in the groundmass are sharply bounded, take on more distinctly the clustering radiating habit of variolitic rocks and are surrounded by a blackened border, full of skeleton-ilmenite and finely divided augite. In such rocks, there are frequently clear traces of flow-brecciation, the several fragments being sharply bounded in some places; in others they merge into the surrounding rock. These rocks show many structures within a short space, glassy, fragmental, or variolitic, solid or filled with lakelets of chlorite. In all these the felspars remain quite clear, and are acid oligoclase or albite. The extreme outer margin of one pillow in Swamp Creek exhibits a structure of which no parallel is known to the writer. It so closely resembles the plan of a pillow-lava that it may be termed the micro-ellipsoidal structure. It is probably a first stage in the formation of variolitic structure, preserved owing to the sudden quenching. The rock is broken up into small ellipsoidal portions about 0·2 mm. in diameter, consisting of radiating fibres of a dark brownish-green colour (chloritised augite ?), surrounded by a ring of clear epidote. This epidote is separated from the epidote in the adjacent micro-ellipsoid by a thin band of grey dusty material, which widens out into tricuspate areas at the point of contact of three micro-ellipsoids, just as does the material between the large

ellipsoidal masses in pillow-lava. Within the micro-ellipsoids are phenocrysts of more or less epidotised plagioclase and fresh augite (Plate xxvi., fig.10).

Another type of structure occurs in the rapidly chilled rocks, particularly in the fragments of spilite in the agglomerates associated with the limestones. This has been already described, and is illustrated in a previous paper (Part iii., p.665, and Plate xxvii., fig.2).

*Occurrences of various types of dolerite and spilite.* - The two widest masses of dolerite are those on Munro's Creek and Hanging Rock. The first is about five hundred yards wide. Its eastern margin, against a fine-grained tuff, is a very fine-grained mass of uralite and chlorite, with a few phenocrysts (1041). A yard from the margin, the grainsize is larger (0·2 to 0·3 mm.), though the rock is still considerably decomposed. From this there is a gradual increase in grainsize inwards, and also an increase in the amount of quartz. A wide zone occurs lying from one hundred to one hundred and fifty yards from the boundary marked by a gneissic (fluxional) structure. The inner quartz-dolerite has the composition given on p.139 (1021), while the rock outside the gneissic band is free from quartz and has a lower percentage of silica (1002). A narrow fine-grained margin appears also on the western side of the mass, and is separated from the invaded rock (tuff-breccia) by a few inches of a finely granular aplitic rock which merges into the tuff. Under the microscope (1182) it is seen to be made up of small (0·05 mm.), equidimensional grains of albite, frequently free from twinning; at other times so finely laminated with albite and pericline twinning as to appear like microcline, save that its optical character is positive. A few small crystals of augite, and a little ilmenite are also present.

The large mass of Hanging Rock, which is half a mile wide, has an acid central portion. The rock figured on Plate xxv., fig.1 (1065), from the central portion of the massif, is much richer in silica than that near the margin, which contains 54% $SiO_2$ (see analysis 145). The grainsize does not vary noticeably across the massif.

The dolerite of the Possum Tunnel and elsewhere, near Bowling Alley Point, has been invaded by a coarse pegmatitic dolerite, consisting of oligoclase-albite (not andesine), augite, and large ilmenite-plates with a little interstitial quartz and plagioclase. The rock is rather crushed, and much veined with quartz, epidote, and calcite.

The long string of spilite-occurrences, running from north of Tom Tiger to the Oakenville Creek, have been already described. The spilite first analysed is one of these (117, N.T.415, Part iii, p.704). It has a complex texture; coarse phenocrysts and glomero-porphyritic aggregates occur in a spilitic groundmass in which are vesicles filled with calcite, and surrounded by fine-grained, subvariolitic, hypocrystalline material (see Part iii., Plate xxvii., fig.1). The spilites of Moonlight Hill have a partially granular, partially ophitic texture, and pass laterally into fine-grained spilitic masses. No special textural features are to be seen in the dolerite that contains axinite in its vesicles, save in the widely differing character of the material filling adjacent vesicles. Quartz, epidote, chlorite, calcite, and axinite occur singly, or in association.

A small sill crossing Moonlight and Madden's Creeks exemplifies best the porphyritic spilites with basaltic groundmass (Plate xxv., fig.4). Its vesicles contain quartz, which also appears to be replacing the rock metasomatically. Both magnetite and ilmenite occurred, but the latter is now changed to titanomorphite. The sill, though only four yards wide, is much more finely granular on the margin than within, though there is no alteration in texture or composition

The spilitic rocks in the Woolomin Series are not so varied in texture. They are rather basaltic in character, and the phenocrysts are not very abundant. In one instance only has a pillow-like mass been found in the Woolomin rocks of the Nundle district. The rock of which it was composed consists of a few phenocrysts, clear plagioclase and uralite, set in a base of the same materials. The felspar of the groundmass is fresh, often untwinned, and very fine-grained (Pl. xxv., fig.3). Other rocks show the same original structure, but are more crushed. A few

coarse-grained dolerites occur among these. They are also greatly shattered, traversed by shearing lines and long bands of crushed minerals. The felspar is difficult of determination, owing to the poor development of twinning, but it can never be said to have a spongy structure. The pyroxene is almost entirely changed to uralite.

*The Variolites and associated Dolerites.*

These rocks form a small group quite distinct from the normal spilite-dolerite series. Two occurrences may be noted as examples. The first is only a single narrow dyke traversing the cherts opposite Lyons' house in Swamp Creek. Variolitic texture is very well shown among the felspars, while the remaining minerals have become almost entirely changed to carbonates. The second mass is much larger and diversified. It occurs in Munro's Creek. The field-relationships have been described above. The breccia-like rock on the eastern margin(1090) consists of fragments of crystalline rock, set in a light yellow brown glass, which is hypocrystalline, in places approaching to the character of the fragments which it includes. The most abundant of these inclusions are those least different from the groundmass. They are porphyritic with albite phenocrysts in a grey hyalopilitic matrix, containing many laths of felspar. The proportion of glassy to crystalline matter, and the extent to which flow-structure is developed, differ considerably in the several fragments, as do also the size and abundance of the phenocrysts. A second type of inclusion is holocrystalline. It contains fewer phenocrysts than the above, and has a pilotaxitic to trachytic base, consisting of albite laths with a little ferromagnesian matter, chiefly epidote and actinolite pseudomorphs after pyroxene. Wide variations occur in the extent of development of the flow-structure and the amount of ferromagnesian minerals. The type passes into the one first described. In addition, there are isolated crystals of albite, which project into the inclusions of the first-described type in a manner which shows that these inclusions were still plastic while they were in the glassy groundmass. There can be little doubt that this is a rock produced by the consolidation of a moving magma, which was shattered and the fragments were

incorporated in the crystallising moving melt, which chilled and solidified rapidly. In other words, it is a flow-breccia. When decomposed, this rock appears in handspecimen like a schistose tuff. A thick band of it crosses the eastern branch of Munro's Creek.

The most peculiar rocks are the variolites. There are several types of these. The most aphanitic stage is a dense, pale green rock containing white spherical spots, which have no definite outlines. It occurs in a narrow pillowy mass on the westernmost tributary of Munro's Creek, and again on the main creek near the Razorback(1034, 1089). Under the microscope, it is seen to possess a grey-green base divided up into acutely angular portions separated by straight colourless rods running in all directions(Pl.xxvi., f 9). These rods are quite sharply bounded, but their nature and composition cannot be determined. They suggest felspar by their appearance, but are untwinned and divided into irregular lengths, each occupied by a single transparent mineral, different in optical orientation from its neighbours. The elongation of these short portions of the rods may be positive or negative. Professor Gregory has described similar structures in the variolite of the Fichtelgebirge(**18**), and Michael Levy in that of Durance(**19**).* These authors suggest that these may be contraction-cracks filled with secondary felspathic material. The same explanation may hold for the rocks under discussion, but it is difficult to account for the absolute rectilinearity of the structures. Where these rods intersect, there are occasionally radiate spherulites of felspar (varioles). The angular spaces between the rods are composed of very fine green fibres, with a radial or curved arrangement about one or more centres, often recalling the arrangement of the line of force about a bar-magnet. They lie in a colourless, weakly birefringent groundmass. The greenish fibres extinguish at small angles, and are probably chlorite. No primary minerals or recognisable pseudomorphs occur in these rocks. In a more crystalline stage of this rock, the chlorite plates are more individualised; large plates are associated with

* For a summary of all the earlier work on variolites, see Gregory and Cole's paper, "Variolitic Rocks of Monte Génèvre," Quart. Journ. Geol. Soc., 1890.

epidote and are probably pseudomorphs after plagioclase. The rod-like structures still persist, but are either less well marked, or are emphasised by the development in them of lines of magnetite, or they are completely hidden by secondary minerals. Other types of variolite are porphyritic; they contain (*e.g.*, 1007) phenocrysts of decomposed augite and plagioclase, in a confused more or less variolitic base, composed of laths and skeletal forms of felspar, together with a little uralite, epidote, and chlorite; a little secondary quartz is scattered about in small irregular patches.

Associated with the rocks just described, is a very beautiful variolite which consists chiefly of felspar with a little interstitial augite. The characteristic radiating structure is well shown (Plate xxvi., fig 7). This rock forms the outer part of a pillow; it is unfortunately too decomposed to be suitable for chemical analysis, and there are in it abundant veins of pennine and clinozoisite. The felspar seems to be oligoclase, but its exact composition cannot be determined optically. In another rock with a similar groundmass there are numerous phenocrysts of albite(1078). The freshest rock, and the one that has been analysed(1109), has a texture intermediate between the variolitic and ophitic types, with a few phenocrysts. These consist of andesine; the felspar of the groundmass is rather more acid, being a basic oligoclase, with a small extinction-angle, but with a refractive index greater than that of Canada balsam. The augite is partly ophitic, partly in narrow, irregular grains or prismoids. There is a little scattered chlorite, but isotropic, probably colloidal, chlorite occurs, with a small amount of carbonates, clinozoisite, epidote, and a trace of pyrites. The analysis confirms the optical evidence of the basicity of the felspar developed, and the absence of any ferric minerals.

There can be little doubt that these rocks are members of the Middle Devonian series, but their greater richness in lime is not at present explicable.

### *The Keratophyres.*

The keratophyres are a varied group of rocks which consist almost entirely of acid plagioclase. They are connected in two ways with the dolerite-spilite series. Quartz-dolerites, becoming

richer in quartz and albite, pass into quartz-keratophyre. Many intermediate rocks have been found. The rarer type of passage is that in which, by decrease in the amount of pyroxene and increase in the iron ore of a spilitic rock, a black slaggy rock is produced, to which the name magnetite-keratophyre may be applied. Far more common, however, is the association of magnetite-keratophyre with keratophyre proper, quite apart from any passage into the spilite-group.

The true keratophyre is represented by the sill at the head of Oakenville Creek. It consists(1013) of almost pure albite, not acid oligoclase as stated in the earlier account. The analysis, making the same assumptions as before, shows that the felspar has the composition $Ab_9 An_1$. There is, in addition, a little magnetite, limonite, chlorite, and carbonates. In some specimens there are little rods of hæmatite, which may be pseudomorphous after hornblende. (There are little pseudomorphs of this character in the porphyries of the Nundle district.) The texture of the keratophyre is trachytic, but not markedly so, and the laths are of uniform size, being about a fifth of a millimetre in length, with a few small phenocrysts (Plate xxvi., fig.11).

Just north of Folly Creek, near the track to Bowling Alley Point, is a slag-like rock(1084) with well marked trachytic habit, consisting of albite, magnetite, and chlorite pseudomorphous after augite. The magnetite is very abundant, and occurs in exceedingly minute but well shaped crystals. The felspar is in clear laths and microlites. This is an example of the passage-type between a spilite and a magnetite-keratophyre. It differs from the usual type of the latter rock in being quite massive, with little or no scoriaceous habit.

The keratophyre-complex by Hyde's Creek yields the most interesting types. The pinkish-white nodular rock to east and west of the magnetite-keratophyre, is made up of small fragments of very trachytic rock, the flow-directions in the several fragments lying without any regard to the flow-directions in adjacent fragments(1108). Each fragment is made up almost entirely of albite laths, the larger laths lying in a matrix of exceedingly minute microlites and a little quartz. The felspar is often very

fresh, but some kaolinisation has taken place, spreading outwards in bands from the cracks separating the fragments of which the rock is composed. The reddish colour of the rock is due to the oxidation of scattered grains of pyrites.

Magnetite enters into these rocks in a variety of ways, one of the most remarkable being that seen in the nodular magnetite-keratophyres (1096) [Plate xxvii, fig.3]. The rock is divided up into roughly polygonal masses about four millimetres in diameter. Each polygon consists of an outer rim, rich in finely crystalline magnetite in a network of albite microlites. There follows within a zone of varying width, consisting of a finely granular mosaic or lathy felt of albite, which sometimes contains large, clear phenocrysts of the same mineral. There is usually no general circumferential or centripetal arrangement of the felspar laths within a nodule, but frequently a general trachytic structure continues without interruption throughout the whole nodule, and may be parallel or inclined to the trachytic arrangement in adjacent nodules. Besides the albite, a little chlorite may occur in this zone. Within this is a narrow passage-zone of felspar laths, sometimes more or less kaolinised, and containing rather abundant dusty magnetite. The inner part of the zone may be coloured yellow by the abundance of the oxidised chlorite. The central portion is of normal magnetite-keratophyre, composed of albite laths and abundant magnetite. Albite phenocrysts occur in this, and may project, quite unaltered, right out into the clear felspathic zone, or may even traverse two or three zones, retaining the general trachytic direction of the nodule. The above is the most complete type of polygonal nodule; in others less well developed, some of the zones may not be present. In a few instances, the central magnetite-keratophyre, with its more or less marked texture, is wrapped round by a zone of keratophyre free from magnetite, in which the laths have a circumferential arrangement. The boundaries of the several zones are never sharp. Where spaces occur between the nodules, they are filled with a mosaic of chiefly untwinned felspar. Except for the abundance of magnetite, this rock is allied in structure with the purely felspathic brecciated keratophyre last described.

There are also rocks of a more obviously brecciated appearance, angular fragments of black rock in a pinkish background. These show a brecciated structure similar to that of the foregoing; that is, they are divided up into areas, in which the general direction of the trachytic texture has no relation to that in the adjacent areas, and this diversity of flow-direction is seen both in the parts rich in magnetite and in those free from that mineral. As in the last rock, also, albite crystals may project from the dark ferruginous part into that surrounding it, which is composed entirely of felspar. The limits of the ferruginous parts are quite irregular; though, in handspecimen, they may appear to be very sharply bounded, under the microscope, they are seen to pass into non-ferruginous parts (Pl.xxvii.,f.4). In a few instances, the magnetite-keratophyre fragments are wrapped round by purely felspathic rock, in which the felspar laths are arranged circumferentially about it. Magnetite may also occur in cracks traversing the rock, sometimes running between adjacent trachytic patches, sometimes cutting across a single fragment. There are also segregations of magnetite lying isolated in areas usually free from that mineral. Chlorite occurs in large flakes. As regards actual mass, the magnetite is considerably less abundant than the felspar, but the very minute grains and crystals are so abundant that they render the whole portion of the rock in which they occur almost black. Fig.6 is a diagram showing the structure of these rocks. For clearness' sake, the size of the felspars has been enlarged proportionately to that of the individual rock-fragments.

Text-fig.6.—Diagram showing the structure of a brecciated magnetite-keratophyre.

A variety of the brecciated structure is seen in a few rocks, in which the fragments of trachytic rock are not in contact with

one another, but are separated by a matrix of minute equidimensional grains of felspar, either untwinned, or twinned with exceedingly minute lamellæ. Quartz may also occur in this mosaic, but its determination is difficult. The trachytic fragments may be entirely felspar, or may be homogeneous magnetite-keratophyre, but generally they are keratophyre with a magnetitic core, and purely felspathic outer parts. Complementary to this type of rock, there is still another (1188) in which the non-trachytic matrix predominates, and is grey-coloured owing to a regular distribution of magnetite throughout: the inclusions are felspathic trachytic keratophyre, and sometimes contain a magnetitic core. Even in this rock there is a concentration into lines between the inclusions, giving a honeycomb-appearance. (Plate xxvii., fig.1).

In other rocks, the magnetite is more evenly distributed, and the rock begins to take on a more slaggy or scoriaceous habit, and its rough, irregular cavities are filled with calcite. After having removed the carbonate by hand, as far as was possible, during the rough crushing of the rock (1086), the remainder was analysed, with the result given(p.139). This confirms the optical determination of the felspar as albite, for the composition of the felspar, calculating from the analysis in the same way as before, should be $Ab_{10}An_1$. The amount of titanium present is rather less than might have been expected from an analogy with the chemical characteristics of the spilitic series. The same features are even more strongly developed in the very richly magnetitic keratophyre shown in Plate xxvi., fig.12. The association of areas rich in magnetite with others poor in that mineral, sometimes merging into one another, sometimes sharply defined, and the strongly marked trachytic texture, with occasional brecciated structure, are also distinctive features. The rock is strongly attracted by a magnet: the felspar is apparently pure albite and water-clear, but the rock is so scoriaceous, and so intimately mixed with calcite, that density-determinations or chemical analysis would be of little use.

Some of the magnetite-keratophyres of this complex contain more or less quartz. In one(1060) near the margin of the mass,

the richly magnetitic areas lie in a matrix of quartz-keratophyre, in which some, at least, of the quartz is of secondary origin. Another of these rocks differs in that the magnetite occurs not only in finely divided masses, but in irregular aggregates from a tenth to a fifth of a millimetre in diameter. The rock(1110) has a brecciated structure, and the magnetite is segregated chiefly in long, irregular bands running between adjacent fragments, and in close association with the secondary quartz and calcite. It also occurs impregnating the central parts of some of the fragments. Apart from the presence of magnetite, the rock is similar to the quartz-keratophyres to be described below.

The magnetite-keratophyre that lies north of the jasper band differs from the above in having an amygdaloidal character. The vesicles are filled with quartz, and sometimes have a selvedge of chalcedony. The rock consists of a felt of albite-laths and small phenocrysts in a matrix darkened by dust-like magnetite; the latter is, for the most part, evenly distributed, but may be aggregated around the vesicles.

The magnetite-keratophyre of Silver Gully is similar to the rock last described. It is associated with a small patch of dense, slaggy, very heavy magnetite-keratophyre, similar to the most ferruginous parts of the Hyde's Creek rocks. As already mentioned, this mass of keratophyre seems to pass into a locally brecciated sill of dolerite, which extends about half a mile northwards. This dolerite has been more or less silicified in places, and more carbonates have been introduced. The dolerite of the Hyde's Creek complex, though it is not so intimately connected with the keratophyre, closely resembles the Silver Gully rock. It is very acid; indeed it may be considered as a passage-rock between dolerites and quartz-keratophyres: it consists of albite, chloritised pyroxene, and abundant interstitial quartz, together with a little ilmenite locally changed to sphene. The rock is rather crushed, and carbonates have been introduced into the zones of granulation.

Adjacent to the dolerite in the Silver Gully complex, is a fairly coarsely granular quartz and felspar rock which appears, at its eastern side, to be a massive quartz-keratophyre-porphyry

but which passes without a break into an obviously brecciated rock, filled with fragments both of igneous rock and of limestone. A microscopical examination of the apparently massive rock shows that it also is brecciated. It consists of large shattered crystals and angular fragments of quartz and felspar in a fine-grained felsitic base. Even more remarkable is the agglomeratic rock on the summit of the ridge between Silver Gully and Pipeclay Creek. This consists of a varied collection of rounded or angular fragments of porphyritic or trachytic keratophyre and magnetite-keratophyre in a matrix of trachytic keratophyre. Though there are no lines of contact with the sedimentary rocks exposed, it seems reasonable to consider this mass as the product of the intrusion of a keratophyre-magma filled with cognate xenoliths.* This is an extension of the conception of a brecciated intrusion which is necessary to explain the structure of the Hyde's Creek keratophyre.

The main series of rocks to which the name quartz-keratophyre is most directly applicable, run along the eastern side of Silver Gully, across Pipeclay Gully to Cope's Creek. Their macroscopic features have been already described. The composition of the rock is fairly uniform throughout, but variations occur. The predominant mineral is acid felspar. This generally, but not always, forms phenocrysts lying in a pilotaxitic, trachytoid or panidiomorphic granular base. With these are sometimes phenocrysts of augite with a large optic axial angle. The plagioclase of the base is rarely easily determinable, being often rather dusty: it does not appear, however, to be more basic than oligoclase. Augite may occur in the base as small prisms, but is generally changed to chlorite: magnetite, ilmenite or titanomorphite may occur in small amount. The greatest diversity arises in the mode of occurrence. A few of the rocks in this mass are free from quartz, but the majority contain it in a manner which raises suspicion as to its primary character. It may be interstitial, or form in little irregular patches against which the felspars are moulded, or it is present in intimate

* Compare with this the "Eruptive pseudo-conglomerate" described by Clements(5), p. 135.

micrographic intergrowth with the felspar. In the last case, there can be no doubt that the quartz is primary. The larger grains apparently replace portions of the felspar-felt, and in no way resemble corroded phenocrysts, but have more the appearance of secondary introductions, especially when they occur in zones characterised by more than the usual amount of calcite or chlorite. Finally, in several of the rocks the quartz-grains are completely surrounded by chalcedony, which extends outwards into the felspar of the rock-matrix. This is clearly a secondary enlargement of the quartz-grains, and we may note at the same time, the abundance of chalcedony in the vesicles of some of the rocks. Chlorite and calcite also occur in the vesicles either singly, or in association with each other.

*The Post-Peridotitic Dolerites.*.

These rocks form dykes in the serpentine, chiefly on the northern slope of Chrome Hill, and also in a small patch of serpentine that occurs west of the Peel River, south of Warden's homestead. They are usually very crushed and altered. The freshest rock(1107) has a very peculiar structure It is partly granulitic, the base consisting of angular or rounded grains of augite in a groundmass of platy felspar. There are a few large felspar-phenocrysts, and some ophitic glomeroporphyritic aggregates of felspar and augite, as well as isolated grains and crystals of augite. The pyroxene is pale in colour, and though there is no noticeable purplish tinge, hour-glass structure may occasionally be seen. The optic axial angle 2V is 51°. No difference is observable between the augite of the phenocryst and that of the smaller grains. Both are very fresh, though chlorite is abundant, at times pseudomorphous after augite. The plagioclase is not easily determinable. Some large zoned crystals occur, showing refractive indices greater than that of Canada balsam, but the extinction-angles do not yield determinative readings. The felspar of the groundmass is very dusty, and is frequently decomposed to a cloudy mass of epidote and clinozoisite. It seems to have the optical characters of an acid andesine. The composition calculated from the chemical analysis (see p.139) is

$Ab_{1\cdot 9}An_1$. Titanomorphite is very abundant, occurring in irregular grains or in long saw-like rows, as if developed from an ilmenite-plate. No undecomposed ilmenite remains.

More common than this are rocks which might be termed proterobases. They are more or less crushed and altered, and contain a reddish-brown hornblende, which forms isolated grains or peripheral intergrowths with the augite. The latter is generally fresh and similar to that in the rock last-described, though its optic axial angle may reach as low as $2V = 42°$. The felspar, on the whole, may be a little more acid. An outer zone of albite sometimes appears around the andesine-kernel, but an exact determination is rarely possible. Ilmenite is generally replaced by titanomorphite, and a very little apatite may sometimes be seen The structure varies from granular to ophitic.

These rocks differ from the post-peridotitic dolerites of the Barraba district, and also from the spilitic group of rocks, though their chemical analysis repeats most of the features seen in the analyses of the spilitic rocks.

## General Discussion.

The observations, of which an account has been given, raise a number of interesting and difficult problems. The most striking feature of the whole series of the Devonian igneous rocks is their richness in soda. This character they share with the spilitic rocks of England, and it will be of interest to see how far the explanations offered for the nature of these rocks are applicable to ours, and what alternative views may be considered.

Messrs. Flett and Dewey consider that the albite in the British spilite-lavas is secondary(2). They believe it to have been produced by a pneumatolytic change affecting the rocks shortly after their solidification. Solutions, rich in soda, traversed the rock, attacking, and replacing by albite, the originally basic felspar, and, at the same time, changing the pyroxene to chlorite, epidote, and calcite. The intrusive albite-dolerites are equally albitised, but, in them, the pyroxenes are rather better preserved. The secondary nature of the albite is seen by its spongy character. Associated with the English albite-dolerites is a hornblende-pro-

terobase (minverite) in which the albite is chiefly primary, though a small amount of albito basic felspar may be recognised. The quartz-diabases in the same series are not albitised at all. By the escape of the sodic solutions from the igneous rock into the surrounding mudstones, adinoles are produced. The occurrence of the minverites shows that albite may crystallise directly from a differentiate of the spilitic magma, although, in the British rocks, according to this view, it was usually segregated into post-volcanic solutions that attacked and replaced the originally crystallised basic felspar. Bowen(22) and others describe the development of albitic facies in the upper portions of doleritic masses, and the escape of the albite into the overlying sediments, producing adinole. Bowen believes that the albitic rocks are the result of the intrusion of gabbroid magma into argillites, and that the water contained in the sediments has taken part in the transfer of the albite-molecule out of the normal magma. Daly supports this view, believing that the examination of sills, from the top to the bottom, will show an upward enrichment in albite. "The submarine origin of the pillow-lavas implies that the magma passed through wet sediments of greater or less thickness. Under these conditions, water-gas must play an important rôle in modifying the magma in the vents, and it seems impossible to doubt that, occasionally, the upper part of the magma-column, and also some of the extruded lava, will become albitised. Meanwhile, the general body of the igneous rock must often be profoundly altered by the absorbed water-gas or hot water, exactly as described by many authors writing of the spilitic masses. . . . . . The writer believes that the spilite rocks are pneumatolytic derivatives of normal basaltic magmas, and that the modifying gas is chiefly water of resurgent, not of juvenile origin."(9, p.340).

The spilitic rocks of the Nundle district differ from the majority of those discussed by Messrs. Flett, Dewey, and Daly, in the almost complete absence of signs of secondary origin of the felspar, and the rocks as a whole are fresh. Clear albite prisms may occur in ophitic intergrowth with undecomposed pyroxene, a thing difficult to explain on the hypothesis of the

secondary origin of the albite, unless, in some circumstances, albitising solutions have no action on pyroxene. Certainly some decomposition-products occur, chlorite, epidote, and calcite, but they are not abundant, save in rocks that have obviously been in solution-channels (*i.e.*, shear-lines, and the boundaries of some sills) or have suffered the intense pressure that affected the rocks of the Woolomin Series. It must be noted, however, that our rocks are rarely, if ever, flows, and, as Messrs. Flett and Dewey have observed, pyroxenes, as a rule, are better preserved in the intrusive than in the extrusive rocks. Further, in the examination of the wide sills, there is no sign of greater albitisation of the upper parts. One cannot say definitely which is the upper part of the great sills on Munro's Creek and Hanging Rock, but it seems clear that the rock is equally albitised throughout a width of more than five hundred yards. The western, and probably upper side of the former mass contains veins of albite-dolerite-pegmatite. Another point of difference from the British spilitic rocks is the albitic character of the felspar in the quartz-dolerites. Certainly, in some quartz-dolerites, zoned felspar occurs, of which the central portion is andesine, but it is not usually present. They are, however, with the single exception noted, the only rocks in which felspar more basic than oligoclase is to be found.

Again, adinole is not developed along the contact of dolerites and cherts. Two specimens were analysed, which should have had every opportunity of becoming albitised had sodic solutions escaped from the cooling magma. These are (A) the chert in the mass between the pillows of spilite, illustrated in Fig.2b, and (B) the secondary chert from the specimen shown in Fig.1, in which the felspars of the invading dolerite(1040) are clear well crystallised prisms of labradorite. C and D are respectively radiolarian chert and cherty shales from the Tamworth Common. (A narrow sill of albite-dolerite occurs here, but, from the descriptions of Messrs. David and Pittman(12), it does not appear to have been in contact with these two rocks). The figures are those determined by Mr. Mingaye. E and F are from slightly altered, and completely altered sediments, that are changed into

adinole where they are in contact with diabases of the Harz Mountains.

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| $SiO_2$ ... | 67·87 | 70·06 | 91·06 | 80·50 | 69 27 | 75·25 |
| $Na_2O$ .. | 1·10 | 1·04 | 0·28 | 1·18 | 2·25 | 7·54 |
| $K_2O$ .. | 2·08 | 1·08 | 0·84 | 1·68 | 4·31 | 0·61 |

It is clear that the cherts from the Nundle district do not contain any noteworthy amount of albite. On the other hand, the presence of the albite-aplite above the Munro's Creek sill, shows that locally there was some slight albitic extrusion from the magma.

Termier has explained(35) the albitisation of some Alpine diabases, by the supposition that soda-bearing soil-waters draining off gneissic areas on to diabases may bring about a replacement of lime by soda, concurrently with the decomposition of the ferromagnesian minerals, and he has brought forward an interesting series of analyses in illustration of this. From the nature of the case, this hypothesis is quite inapplicable to the explanation of the Nundle rocks.

It seems permissible to suggest that albite in spilitic rocks may be either a direct magmatic crystallisation, or may have been concentrated into the magmatic aqueous solutions, and have then replaced the first-formed basic felspar. The albite of the Nundle dolerites and spilites, like that of the British minverites, seems to be chiefly primary. This does not preclude the possibility that it may be largely secondary in spilitic rocks in adjacent areas. The conditions, that would determine the one mode of crystallisation or the other, probably depend on the amount of water in the spilite-magma, its source, and its mode and time of escape.

In the keratophyres, there can be no doubt that, at the end of the sequence of differentiations, the magma was very hydrous, and post-volcanic processes were very active. The felspar of these rocks is almost pure albite, but even here there is no evidence of the secondary nature of the felspar. Neithammer, from a study of some Javanese rocks, concludes that the keratophyres may be albitised porphyrites(23). Sundius states that the felspar

of the magnetite syenite-porphyry of Kiruna, Lappland, though originally acid, has been still further albitised(22) Nothing analogous to the features claimed by these authors as evidence of albitisation, has been noticed in the keratophyres of the Nundle district.

The development of magnetite in the keratophyres presents many features of interest. So far as can be learnt, the only rocks, at all analogous to these, are the Pre-Cambrian magnetite-syenite porphyries of Lappland, and a few isolated and less investigated occurrences in the Urals and elsewhere The analogy is very clear, if we compare our rocks with the descriptions and illustrations in the papers of Sundius(23), Geijer(24, 25), and Lundbohm(26). Sundius, while employing Geijer's term, magnetite-syenite-porphyry, suggests that keratophyre would be a more suitable designation. It will be of interest, therefore, to summarise the views that have been put forward as to the origin of the Scandinavian rocks. The magnetite-syenite-porphyries are in intimate association with great deposits of iron-ore, and the explanation depends on the view adopted as to the origin of the iron-ores. Backström considered the iron-ores were of hydro-pneumatolytic origin, belonging to the last phase of volcanic activity(27). The volatile iron-salts rose through the igneous rocks, and, coming into contact with the sea-water above, were precipitated as magnetite. This hypothesis was supported by De Launay(28). On the other hand, Hogbom considered the ore was the result of a differentiation from a syenitic magma(29), and Stutzer supported this view, adding to it the statement that pneumatolysis has played an important minor rôle in the formation of the ore(30). Geijer has studied the question in great detail. His monograph on the Kiruna field(31) is, unfortunately, not accessible in Sydney, but he has published an abstract of it in Economic Geology(24), and, more recently, a general review of the mode of occurrence of the iron-ores of Lappland(25). He supports the view of the magmatic origin of the iron-ores, as also of the magnetite-syenite-porphyries, believing that the latter differentiated out from the normal syenite-porphyry of the district, and had a lower temperature-range of crystallisation. He

cites the researches of Lenarcic(32), and Day and Allen(33) on the lowering of the viscosity produced by the presence of a small amount of magnetite in an albite-melt, and notes that the eutectic albite-magnetite ratio of three to one, as determined by Doelter(34), seems to be a frequent one in the magnetite-syenite-porphyries. At the same time, he recognises the presence of a certain amount of pneumatolytic action, affirming that the ores stand in pegmatitic relation to the parent-magma, there being evidence for the presence of a considerable amount of magmatic water. (Apatite occurs with the ores.) His view differs from that of Stutzer chiefly in the advocation of an effusive, not intrusive, origin for the syenite-porphyries.

The most significant features of our rocks seem to be the following: they solidified from a magma under non-uniform pressure, and hence are not only strongly trachytic, but were broken up as they solidified, and the keratophyres now consist of closely compacted, minute fragments of trachytic rock, usually without any matrix, occasionally with a matrix of non-trachytic acid keratophyre, a consolidation of the residual magma under static conditions. Most of the fragments have preserved the straight direction of the flow-structure, some have been bent, some have been actually rolled up into a concentric arrangement, and this is most frequent when the fragment has a kernel of magnetite-bearing rock. The magnetite-keratophyre forms the central portion of the keratophyre-mass; around it is a zone of parti-coloured nodular or breccia-like mixtures of magnetite-keratophyre with purely albitic rock. In these, the distribution of the magnetite is most irregular, but, in the main, it is suggestive of the occurrence of two periods of crystallisation. It rarely, if ever, occurs as inclusions in the crystals of felspar, but lies in an extremely divided state between the felspar-laths. Part of it is segregated into nodules of rounded or irregular shape, sometimes broken across by the brecciation, and here showing a sharp fractured boundary, but more usually without any sharp boundary, passing out into the albitic rock, which may have a continuous rectilinear flow-direction, or may bend to more or less encircle the dark portion. This seems to show that the presence

of magnetite toughened the rock against brecciation, which occurred either during the crystallisation of the felspar, forming the kernels around which the last formed laths might wrap themselves, or immediately after the consolidation of the felspar, in which case the trachytic structure of the particular fragment would pass unhindered through the magnetitic nucleus. The latter is the more usual feature. The first epoch of crystallisation of the magnetite seems to have been a magmatic one: the magnetite-keratophyre and keratophyre proper must be differentiates from a common magma, and the peculiar mixed rocks form the transition-zone of incomplete differentiation. After consolidation and brecciation, there still remained a residual magma which consolidated between the fragments. This granular mesostasis may consist of quartz and albite, of quartz, albite, and magnetite, of quartz and magnetite, or of magnetite alone The last two types of matrix sometimes form in such narrow crevices between the fragments, or in cracks traversing them, that it seems most probable that they are of the nature of hydro-pneumatolytic veins. In confirmation of this, we may note that they slightly impregnate the rocks on either side of the vein. In one specimen, the mesostasis retained nearly all the magnetite(1188). The nodular segregations of magnetite are quite different from those in the Scandinavian rocks, which, according to Backstrom, are vesicles filled by pneumatolytic deposits of magnetite, but, according to Geijer, are "concretionary bodies in the porphyries, and have crystallised under igneous conditions, and pass into the normal groundmass on the one hand, and into true vesicles on the other."(**25**, p.715).

Within the zone of these mixed brecciated keratophyres, lies the main mass of magnetite-keratophyre of the Hyde's Creek complex. It is much more uniform, and brecciation is not so very marked a feature. The slaggy, vesicular character is doubtless due to the former presence of magmatic gases, and the rough, non-amygdaloidal shape of these cavities is, perhaps, explicable on the assumption that the rock moved in jolts by successive brecciations of almost solid rock, and not entirely by steady viscous flow.

In the quartz-magnetite-keratophyres, brecciation is rarely seen. The vesicles are abundant, and are rounded or amygdaloidal. All the magnetite seems to have crystallised in the earlier period. As we pass to the quartz-keratophyres, there is increasing evidence of the action of silicifying waters, not only in the filling of the vesicles with quartz and chalcedony, but in the attacking of the rock itself, the formation of rings of secondary silica, quartz or chalcedony around the original quartz-grains, and the replacement of small parts of the rock-fabric by a finely granular quartz (agate?) mosaic.

The jaspers associated with the keratophyres are the last product of the spilite keratophyre magma. Narrow veins of jasper occur in the keratophyre, and large independent masses are developed, which were deposited by successive bodies of siliceous solutions, rising through fault-planes, metasomatically replacing the country-rock, and depositing quartz and chalcedony, together with the last of the iron-ore, now completely oxidised to hæmatite. The last of the magmatic solutions, too feeble to form jaspers, have merely jasperised, and reddened, with hæmatite, the banded radiolarian cherts.

Thus the evidence of our magnetite-keratophyres series leads to the conclusion that they primarily originated by magmatic differentiation, but that hydro-pneumatolysis played an important minor rôle. This accords, to a great extent, with the views of Hogbom, Stutzer, and Geijer, as to the origin of the Lappland rocks. The structures developed have been explained as the result of varying degrees of viscosity in the crystallising magma. Recapitulating, we have the following table :—

1. Pure albite-magma, with no vesicles or sign of pneumatolysis. Viscosity extremely high, amounting to partial rigidity; brecciation a very marked feature. The trachytic structure is probably the result of crystallisation under non-uniform pressure, rather than actual flow.

2. Albite-magnetite-magma, with a few irregular vesicles, and slight evidence of pneumatolysis. Less brecciation than in No. 1, and more evidence of viscous flow.

3. Albite-magnetite-quartz-magma, with abundant smooth-walled vesicles, and evidence of the presence of magmatic water. Still further diminished viscosity, brecciation practically absent, and flow-structures more obvious.

4. Quartz-albite-magma, with abundant amygdules filled with silica, and evidence of the former presence of much magmatic water. No sign of brecciation, but every indication of considerable fluidity.

5. Quartz, chalcedony, and hæmatite, deposited from aqueous solution.

The knowledge of the relation between magma-viscosity and chemical composition is at present very imperfect(40), particularly in regard to the quantitative effect of fluxes, such as water; nevertheless, the sequence given above seems to accord with what might have been anticipated.

So far, only those jaspers that are immediately adjacent to the spilites or keratophyres can be said to have been derived from this source, and such jaspers are as yet known in the Bowling Alley Series only. The mode and period of origin of the far more abundant jaspers of the Woolomin Series are not yet known. They show many of the features common to the other jaspers, though they are more uniform in character, and less vein like. The writer concurs with Professor David's present opinion, that they are mainly of secondary origin, alteration-products or metasomatic replacements of country-rock. They can hardly be merely ferruginous, abyssal oozes, as formerly suggested.

The formation of ferruginous jaspers and iron-ores by solutions derived from spilitic magmas is not without analogy. The same mode of origin has been claimed for much of the Lake Superior iron-ore(37), as also for the ores of the Rhenish Schiefergebirge in Germany(39) and elsewhere. In these cases, however, the iron-bearing solutions are believed to have escaped from basic lava-flows, and not after extreme differentiation.

Difficulties arise when one endeavours to determine the conditions under which the series of eruptions took place, which produced the rocks described. The spilite-pillows must have invaded sediments that were still watery, and capable of fluid

movement; therefore, the magma must have come near to the surface (the sea-bottom), during the period of deposition. The more deep-seated magma (the dolerites), encountered consolidated sediment, and have rough, shattered lines of contact with the rocks they invade. The keratophyres, in particular, must have formed at some depth, and only after the complete consolidation and some faulting of the specimens. But the stratigraphical record shows that there was no important faulting or folding from Middle Devonian to Lower Carboniferous times, and we must accordingly consider these faults as merely local movements around the centres of Middle Devonian, submarine, igneous activity.

The discovery of the agglomeratic keratophyre, between Silver Gully and Pipeclay Creek, throws some doubt on the former assumption of a single ejectamental origin of the "tuffs," "breccias," and "agglomerates" of the Devonian stratigraphical succession. When first these rocks were discovered in the Tamworth district, they were considered as sills by Professor David(**38**), though later, upon the evidence of their microscopic structure, he stated that they were tuffs, and termed "intrusive tuffs" certain occurrences in which the relation of the igneous to the sedimentary rock seemed to be an intrusive one. More recently, the so-called tuffs in the Silurian Series, east of the Jenolan Caves, have been proved by Mr. Sussmilch to be really strongly differentiated, intrusive porphyries full of inclusions, not only of cognate igneous rocks, but of fossiliferous limestone, and the enclosing cherts and slates. The writer has seen these, under Mr. Süssmilch's guidance, and has noticed some analogy (first suggested to him by Professor David) between them and the agglomeratic rocks of the Tamworth Series. This analogy does not amount to a parallelism, however. In an earlier communication, the writer suggested that the apparently intrusive character of the acid tuffs into the Devonian chert might be due to the drying and cracking effect of hot ash falling on to damp mud. Other exposures have now been found, in which this explanation is inapplicable. In Swamp Creek, for instance, is a mass of acid igneous rock, resembling what has been termed "acid tuff," but

clearly intrusive into the chert, and containing fragments of *Heliolites*, etc. Microscopically, it is entirely crystalline, and consists of shattered and corroded grains of quartz and albite in a finely granular felsitic mosaic. One may also recall the brecciated keratophyre that passes into calcareous agglomerate near Silver Gully. Another significant feature is the almost entire absence of glassy matter from these "tuffs" and "breccias," and the frequency with which fragments of keratophyre, and even magnetite-keratophyre occur in them They have been found in the "tuffs" of the Moonbi, Attunga, Manilla, and Bingara districts, and also in the Baldwin Agglomerates. Though, at first sight, the term "intrusive tuff" may seem a contradiction in terms, yet intrusion-breccias are well known, and considerations similar to those explaining the close relation of intrusion and extrusion in suboceanic vulcanicity (see p.124) may assist in the explanation of this apparent anomaly.

Further evidence from the field and laboratory is necessary, before these rocks can be profitably discussed.

*Summary and Acknowledgments.* - The spilitic series of eruptions in the Nundle district included spilites, dolerites, and keratophyres. So far as can be seen, they are all intrusive into the sediments, and certain spilites intrusive into soft muds, have produced pillowy masses. They are nearly all rich in albite, which appears to be chiefly primary. They do not show at all clearly the evidence for the secondary character of the albite described by Messrs. Flett and Dewey, or that noted by Termier; nor is there evidence that the soda-content of the magma has been segregated in the manner discussed by Daly. Magnetite-keratophyres occur, and their development was brought about by magmatic differentiation assisted by pneumatolysis. Many of their features recall the magnetite-syenite-porphyries of Lappland. An attempt is made to explain their varied structural features by a consideration of magma-viscosity. The formation of ferruginous jasper-veins is described as a post-volcanic process. No complete account can yet be given of the mode of eruption of the rocks, and, in particular, of the manner of formation of the associated breccias.

The writer must gratefully acknowledge the help given by Dr. Flett (Edinburgh), Mr. Harker (Cambridge), and Dr. Nils Sundius (Stockholm). To Professor David, he is indebted for help and counsel, both in the field and in the laboratory, and for all facilities for research in the Geological Department of the University of Sydney.

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## APPENDIX.

### ADDENDA AND CORRIGENDA TO PARTS i., ii., iii.

Owing to the writer's absence from the State, it was impossible for him to see the proofs of the first three Parts of this series, and he regrets that a considerable number of errors appear in the published work. The following corrections should be made :—

#### Part i.

P. 490, line 13 above the base—after "study", read "over wide areas".
P. 499, line 9—for "schlueteri", read "schluoteri".
P. 504—delete the last sentence.
P. 511, line 3—for "peridolites", read "peridotites".
P. 516, reference 16—for "opiolischen" read "ophiolitischen".

#### Part ii.

P. 575, line 10—for "lens" read "limestone".
P. 576, line 21—for "1000", read "2000".
P. 581, line 2—for "they are", read "it is".
P. 582, line 33—for "hartzbergite", read "harzburgite".
line 34—for "herzolite", read "therzolite".
P. 592, line 5—for "(33). No", read "(33), no),".
P 594, line 18—for "Nundle", read "Woolomin".
Pl. xxii.—The colouring denoting the Woolomin Series has been extended over the zone between the serpentine-line and the eastern limit of the Nundle Series. This zone consists of the rocks of the Bowling Alley Series. A small patch of serpentine has been omitted; it occurs a mile south of Cope's Creek, co-linear with the other masses of serpentine.

#### Part iii.

P. 663, line 10 from base—delete "primary or secondary".
line 2 from base—delete "mineralogical and".
P. 664—delete the first footnote.
P. 664—in second footnote, for "Mining Museum", read "University Museum".

P.668, line 8—for "(35)", read "(34)".
P.671, line 1—for "bending", read "banding".
P.671, line 29—for "marks", read "makes".
P.672, line 22—for "chrysolite", read "chrysotile".
P.642, line 31—for "bastite", read "magnetite".
P.673, line 31—for "chrysolite", read "chrysotile".
P.675, line 15—after "makes", read "conspicuous".
P.676, line 29—for "3·1", read "5·1".
P.678, line 3—for "chrysolite", read "chrysotile".
P.691, line 7—for "Narsatas", read "Nacatas".
P.692, line 10—for "Narsatas", read "Nacatas".
P.702, line 13—for "sanidine", read "andesine".
P.704—Analyses 2 and 3 have been interchanged. "Spilite, Tregidden" is that commencing with $SiO_2$ 47·56% (to which must be added $Fe_7S_8$ 0·06%). "Spilite, Mullion Island" commences with $SiO_2$ 48·58%). Analysis 4 (M.B.12) CaO and MgO interchanged, read MgO 9·00% CaO 7·46%.

Analysis of pitchstone—for Walkom, read Browne.

P.705—Correct:—

N.T.383—for 100·42, read 101·33.
N.T.280—for 99·99, read 98·69.
M.B.197—for 99·89, read 99·79.
N.T.321—for 101·68, read 101·71.

P.706, N.T.118—for 99·31, read 99·39.
P.706, M.B.36—for 100·81, read 100·89.
P.706, Rodingite, Dun Mt.—delete NiCoO 0·28%.
P.720, line 6—for "fossiferous", read "fossiliferous.".
P.721, line 21—for (p. ), read (p.668).
P.722, line 17—for "some", read "come".
P.723, Explanation of Plate xxvii.—Figures 5 and 6 are interchanged.

The following points may be noted, in which some modification or addition is required in the statements made;—

P.496—The stratigraphical disturbance in the Nundle region is greater than formerly realised, and the details of the succession must be taken with reserve. Particularly is this the case with regard to the breccias.

P.497—The abundance of *flows* of spilite-lava has been disproved in the communication herewith. Recent work shows that the identity of Bowling Alley Point limestone with that of Tamworth and Moore Creek can no longer be maintained. The absence of medium-grained tuff from the Tamworth Series is open to question.

P.500—The conformity of the Baldwin Agglomerates on the Tamworth Series has now been proved.

Pp.576 and 580—See note to p.496.

P.573—Abundant radiolaria have now been found in lenticular limestone beds in the clayshales near Nundle.

Pp.578-9—For reasons given in the paper herewith, the explanation suggested for the mixture of tuff and chert is withdrawn.

P.592—Another small pipe of basalt, about fifty yards in diameter, occurs by Hyde's Creek, at the western side of the alluviated plain.

P.676—The conclusion that serpentine does not increase in density to a noteworthy extent in passing from chrysotile into antigorite is open to question. Professor Becke* and Professor Grubenmann† hold the contrary view. The former gives the specific gravities of chrysotile and antigorite as 2·57 and 2·64 respectively; the latter gives 2·50 and 2·60. Leitmeier's collection of data on this point‡ shows that the evidence is rather incomplete.

P.680, line 25—Near the head of Oakenville Creek at Hanging Rock is a pyroxenite that consists almost entirely of diallage, together with a little hypersthene (1168).

P.696, line 6—To the list of porphyries may be added the following:—

Quartz-mica-porphyrite occurs on the eastern side of Munro's Creek. It is a grey rock, spangled by abundant plates of biotite. Under the microscope (1173), it shows idiomorphic plates of biotite, which is almost uniaxial, and contains abundant inclusions of zircon which are surrounded by dark haloes, also apatite and magnetite. A few phenocrysts of plagioclase and quartz are also developed. The base consists of finely divided plagioclase, with a little quartz and prisms of apatite and minute flakes of biotite. Carbonates occur in abundance. In hand-specimen this rock resembles a minette.

P.698, line 28—Insert:—An odinite dyke (1059) intersects the spilite on the Hanging Rock road. It is remarkable for the frequency with which the augite crystals occurred twinned on the (101) and (122) planes, producing cruciform or star-like aggregates.

P.703—The detailed account of the Tertiary volcanic rocks of the Western Coalfield§ shows their identity with the basalt-thoralite teschenite series of rocks which are developed in the Liverpool and Mount Royal Ranges. The list of analyses given is especially worthy of attention.

* Becke, Die Krystallinen Schiefer. I. "Ueber Mineralbestand und Structur." Denkschr. Matt.-Naturw. Klasse, K. Akad. der Wiss. Wien, 1903, p.21.

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‡ Leitmeier, Article on "Serpentin." Handbuch der Mineralchemie, Bd. ii., pp.387-403.

§ J. E. Carne, Memoirs of the Geological Survey of New South Wales, No.6, pp.71-152, and list of analyses on p.93.

## DESCRIPTION OF PLATES XXV.-XXVII.

### Plate xxv.

Fig. 1.—Intersertal Quartz-albite-dolerite(1065); centre of Hanging Rock. ( × 20), polarised light.

Fig. 2.—Ophitic and spilitic albite-dolerite(1028); west of Swamp Creek Falls. ( × 20).

Fig. 3.—Glomero-porphyritic spilite (155); Woolomin Series, Munro's Creek. ( × 12).

Fig. 4.—Spilite with basaltic texture(1029); narrow sill in Moonlight Creek. ( × 30).

Fig. 5.—Holocrystalline spilite(1055); central part of pillow, Happy Valley. ( × 20).

Fig. 6.—Hypocrystalline spilite(1015); narrow sill(?), Munro's Creek. ( × 24).

### Plate xxvi.

Fig. 7.—Variolite(1025); margin of a pillow, Swamp Creek. ( × 30).

Fig. 8.—Hypohyaline semi-variolite (1039); outer margin of pillow, Swamp Creek. ( × 12).

Fig. 9.—Variolite with rod-like structures(1034); Munro's Creek. ( × 30).

Fig. 10.—Micro-ellipsoidal spilite(1044); margin of pillow, Happy Valley. ( × 30).

Fig. 11.—Keratophyre(541); Hanging Rock. ( × 30), polarised light.

Fig. 12.—Magnetite-keratophyre(1075); Hyde's Creek. ( × 30).

### Plate xxvii.

Fig. 1.—Magnetite-keratophyre(1186); Hyde's Creek. ( × 8).

Fig. 2.—Quartz-keratophyre(1088); Silver Gully, polarised light. ( × 50).

Fig. 3.—Nodular magnetite-keratophyre(1096); Hyde's Creek. ( × 9).

Fig. 4.—Magnetite-keratophyre(1100); Hyde's Creek. ( × 18).

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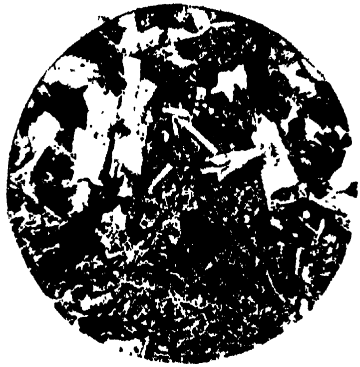

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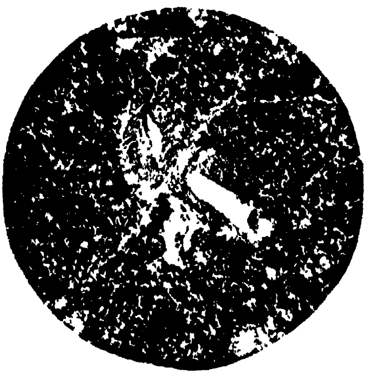

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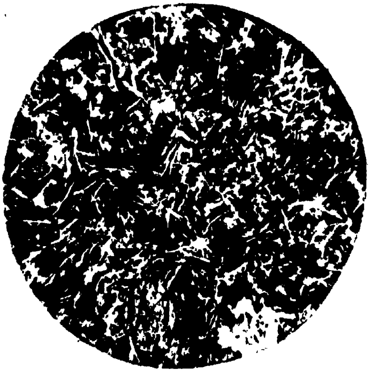

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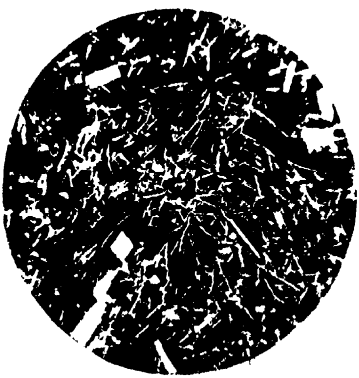
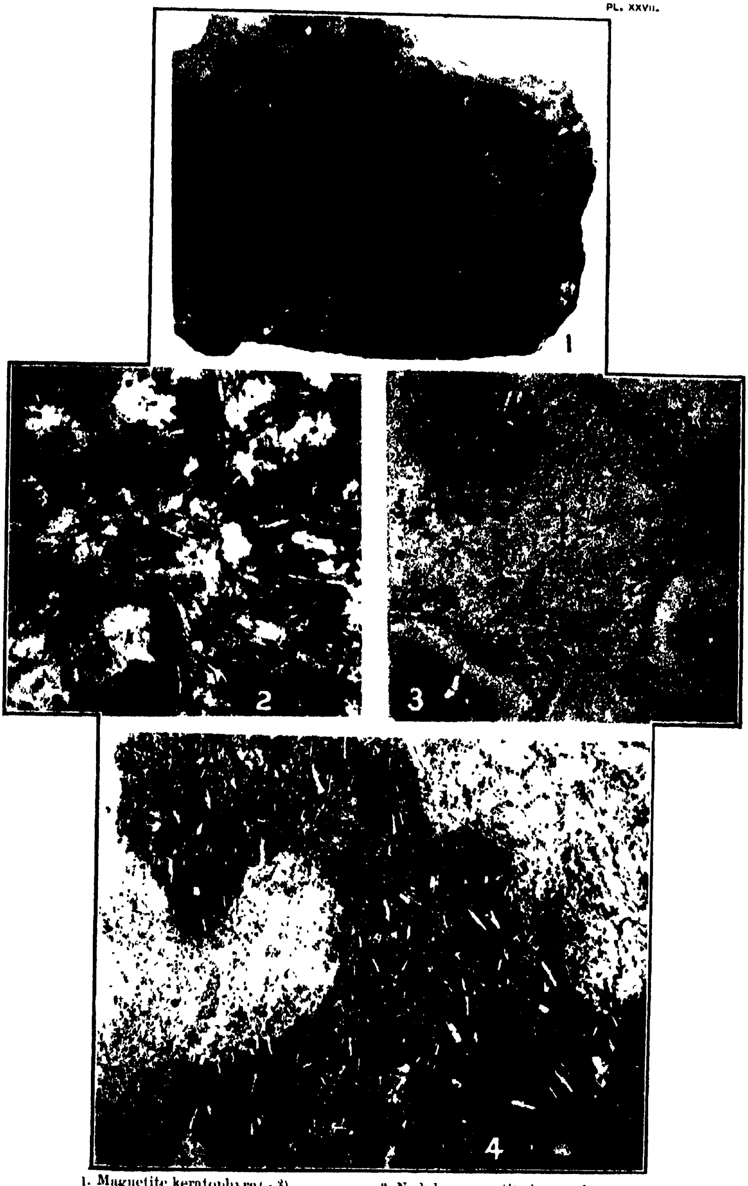


6.

1. Intersertal Quartz-albite-dolerite (× 20).
2. Ophitic and spilitic albite-dolerite (× 20).
3. Glomero porphyritic spilite (× 12).
4. Spilite with basaltic texture (× 30).
5. Holocrystalline spilite (× 20)
6 Hypocrystalline spilite (× 24).



1. Magnetite keratophyre (× ⅔)
2. Quartz keratophyre (× 50)
3. Nodular magnetite-keratophyre (× 9).
4. Magnetite keratophyre (× 18)

[*From the Proceedings of the Linnean Society of New South Wales, 1915, Vol. xl., Part 3, September 29th.*]

# THE GEOLOGY AND PETROLOGY OF THE GREAT SERPENTINE BELT OF NEW SOUTH WALES.

## PART V. THE GEOLOGY OF THE TAMWORTH DISTRICT.

BY W. N. BENSON, B.Sc., B.A., F.G.S., LINNEAN MACLEAY FELLOW OF THE SOCIETY IN GEOLOGY.

(Plates xlix.-liii.; and fifteen Text-figures.)

CONTENTS.



## Introduction and previous Literature.

Tamworth, now a prosperous town of more than nine thousand inhabitants, is one of the old country-towns of the State. It lies on the Peel River at the foot of the Moonbi Ranges, almost due north of Sydney, and at a distance therefrom by rail of two

hundred and eighty-two miles. Though small amounts of gold and copper have been discovered in the neighbourhood, it has never been in any way a mining centre, and its prosperity has been due to its pastoral and agricultural industries. In this respect, the district falls into three divisions: the hilly north-eastern part, composed of granite and slaty rocks; the gently undulating south-western part, chiefly made up of clayslates; and the wide flood-plains of the Peel and Cockburn Rivers that intersect the district. The first two of these divisions were devoted to sheep- and cattle-raising, and to a small amount of dairying, but now, much of the second division, and the flatter portions of the first, are devoted to the cultivation of wheat. The deep alluvium on the flood-plain produces abundant crops of lucerne.

The district first attracted the attention of geologists when the Rev. W. B. Clarke passed through it in 1852, on his way to investigate the gold-fields of Barraba and Bingara. He noted the large masses of limestone on Moore Creek, to the north of the district, and compared them with the Devonian limestones in the Murrumbidgee valley(1). His collections of fossils were described by Professor De Koninck of Liège(2), whose results, first published in 1876-7(2), were translated into English, and appeared as a Memoir of the Geological Survey of New South Wales(3). He described five species of corals as coming from Moara or Mowara Creek, north of Tamworth. A little doubt has arisen as to the spot indicated by this name(11), but there seems no reason to think it other than what is now termed Moore Creek. In his reports, Clarke rendered the original name of the stream by the spelling "Moura" or "Mouara," and an old map shows the name "Mooar."

Very little geological work was done in the district for the next forty years, though collections were made by Mr. D. A. Porter, of Tamworth, of the minerals and fossils of the district, among which he found hyalite occurring with chromite at Moonbi(4), and a new species of coral, described by Mr R. Etheridge, Jun., as *Diphyphyllum porteri*, in the limestone in the Tamworth Common(5).

In 1893, in an address to this Society, Prof. David suggested that the jasperoid slates of the Bingara, Barraba, and Nundle District, which pass through the eastern portion of the area now under discussion, may be altered abyssal deposits(6). Three years later, he discovered that, not only do the jasperoid rocks contain numerous spherical casts, probably replacing radiolaria, but there is a large development at Tamworth of claystones and cherts, and siliceous limestones, containing abundant radiolarian remains, which he briefly described(7). He stated that there appeared to be two beds of coral limestone, one of which was greatly altered by the metamorphosing effect of the New England granite. The thickness of the limestone he placed between 100 and 1000 feet, and added four more forms to the list of fossils. He further remarked: "The claystones and cherty rocks, both above and below the limestone, have also been much altered by innumerable granite sills for a zone over five miles in width measured at right angles to the junction line between the sedimentary rocks and the granite. . . . The sills vary from a fraction of an inch up to several feet in thickness, and at first sight have every appearance of being regularly interstratified with the sediments. A careful examination, however, at once revealed their intrusive character, as they trespass slightly across the planes of bedding, and have slightly altered . . . the sedimentary rocks both above and below them." In another paper he said: "The whole zone for several thousands of feet is half sill, half sediment."(8) So far, however, these apparently intrusive rocks do not appear to have been subjected to microscopical examination.

In 1899 appeared the classical paper on this district, namely, the account given by Professor David and Mr. Pittman conjointly(9). With this there is a geological map of the area. The authors showed that there is an anticline in the valley of Seven Mile Creek, east of the town, and adjacent to the boundary of the granite. Metamorphosed limestone occurs on either side of the axis. Above this, there continues a series of radiolarian cherts, claystones, and lenticular patches of limestone, interspersed with igneous rock. This dips steadily to the west,

and a thickness of 9,260 feet is stated to occur between the anticlinal axis and Spring Creek in the Tamworth Common. Here is a great fault, east of which the limestones appeared again, followed by more radiolarian sediments and interstratified igneous rocks. This limestone is shown to be on the same horizon as that at Moore Creek, and is believed to be also the equivalent of the limestone in Seven Mile Creek. The microscopical examination of the igneous rocks made by Mr. Card having revealed their clastic nature, they are now stated to be felsitic tuffs, but it is still held that they are often intrusive or crushed into the sediments, and pictorial evidence of this is given. The new view, however, removed them from any direct relation with the Moonbi granites. While formerly *Lepidodendron* was found only above the radiolarian rocks, it was now shown to occur within them. On the grounds of the association of the radiolarian chert with coral limestones, the absence of coarse terriginous sediments, the abundance of plant-remains, and the presence of ripple-marking, it was concluded that the radiolarian rocks "were deposited in clear sea-water, which, though sufficiently far from land to be beyond the reach of any but the finest sediment, was nevertheless probably of not very considerable depth." Finally, they discovered certain coarse agglomerates on the hills to the north of Tamworth, which they considered to be unconformable on the clayslates, and probably the basal beds of the Carboniferous System.

The radiolaria in these rocks were investigated by Dr. Hinde, who described fifty-three species, all new to science(**10**). This does not exhaust the radiolarian fauna of the district, however, for additional forms, not yet described, have been noted by Professor David and Dr. Jensen.*

The fossils in the limestones at Moore Creek, Tamworth, and Moonbi, collected by Messrs. David, Pittman, Porter, Beedle, and Etheridge, were described by the last-named, who found nineteen species of corals to be present, most of which were new to science. He considered that the limestone of Moore Creek

* Verbal communication.

probably much nearer to the true stratigraphical succession, though even here are faults, the extent of which cannot yet be determined, which render all estimates of relative thickness of strata very unreliable. The absence of many good horizons, and the lateral variation of some of the formations are additional causes for uncertainty. On this account, we can no longer accept, as final criteria, the distinctions previously made between the cherts of the Tamworth Series and the mudstones of the Barraba Series, or between the pyroclastic rocks of the Barraba and Tamworth Series and the Baldwin Agglomerates. In spite of this, however, the general facies of a series of associated rocks is usually conclusive. It has been found necessary to separate the limestones of Moore Creek and Tamworth from those in the Moonbi (Nemingha) district, the stratigraphical evidence confirming Mr. Etheridge's conclusion, drawn from palæontological evidence, that the latter were on a lower horizon. There is reason to believe in the occurrence of a third limestone-horizon, the relation of which to the limestone of Moore Creek is not yet obvious. The three limestone-horizons have been termed the Nemingha, Moore Creek, and Loomberah horizons respectively. The last-named is as yet but little known, and its description is reserved until the study of the Parish of Loomberah is made. The several divisions of the formations developed will now be discussed in chronological order.

### 1. *The Eastern Series, partly of Lower Devonian age.*

It has been assumed in previous papers, that the rocks east of the serpentine, comprising jaspers, and phyllites, are largely of Lower Devonian age, and, to the Lower Devonian rocks proper, the name Woolomin Series has been applied. Unfortunately, they are so intensely folded and faulted, and have thrust in among them so much that seems to be derived from the Middle or even Upper Devonian Series, that it has not seemed worth while, at present, to attempt to disentangle the Woolomin Series from the others, if such a series should really exist. The whole complex, therefore, will be considered together under the term Eastern Series. The following discussion refers only

to the nature and distribution of the several types of rocks developed.

One of the most striking features is the presence of a large amount of basic rock. This forms long intercalations scattered throughout the Eastern Series as shown (diagrammatically) on the Map (Plate I.). These consist of tuffs, breccias, and spilitic rocks, many of which, though more or less altered, are very similar to rocks occurring in the Middle Devonian Series. In the neighbourhood of the granite, they have been changed, into amphibolites, the zone of metamorphism extending from half a mile to a mile from the granite. This amphibolite occurs, for instance, in the north-eastern corner of the Parish of Nemingha, intercalated with mica-schist, and other masses run southwards through portion 155. Where the basic rocks cross the creek in portions 147 and 190, they form several narrow bands of spilite interstratified with jasper and chert. There is no clear evidence of pillow-structure, but some suggestion of it. South of this, spilite crosses Spring Creek as a thick band, partly schistose, partly massive, with some trace of pillow-structure. It is intersected by bands of jasper, and interstratified with highly crushed banded cherts, and with tuff-breccias like those of the Middle Devonian Series.

South of the watershed of Spring Creek, is a sharp hill, marked by a thicket of pine-trees. Here the rock is quite different, partly a tuff-breccia, partly a rather devitrified flow-breccia, of which the brown glass contains crystals of quartz and altered felspar, and pseudomorphs after felspar-augite. This zone of tuff-breccia is of great width, and is interstratified with cherts. It extends southwards across Oakey and Nemingha Creeks, in the beds of which it is well exposed. Many masses of spilite occur with some approach toward a pillowy structure, and intersected by abundant veins of secondary chert. The basic breccia is cemented into a uniformly resistant rock, which makes bold rounded outcrops.

A very perplexing hill is that east of the northern end of the serpentine-belt. At its western base is a large mass of altered basic rock, probably of Middle Devonian age. Above these are

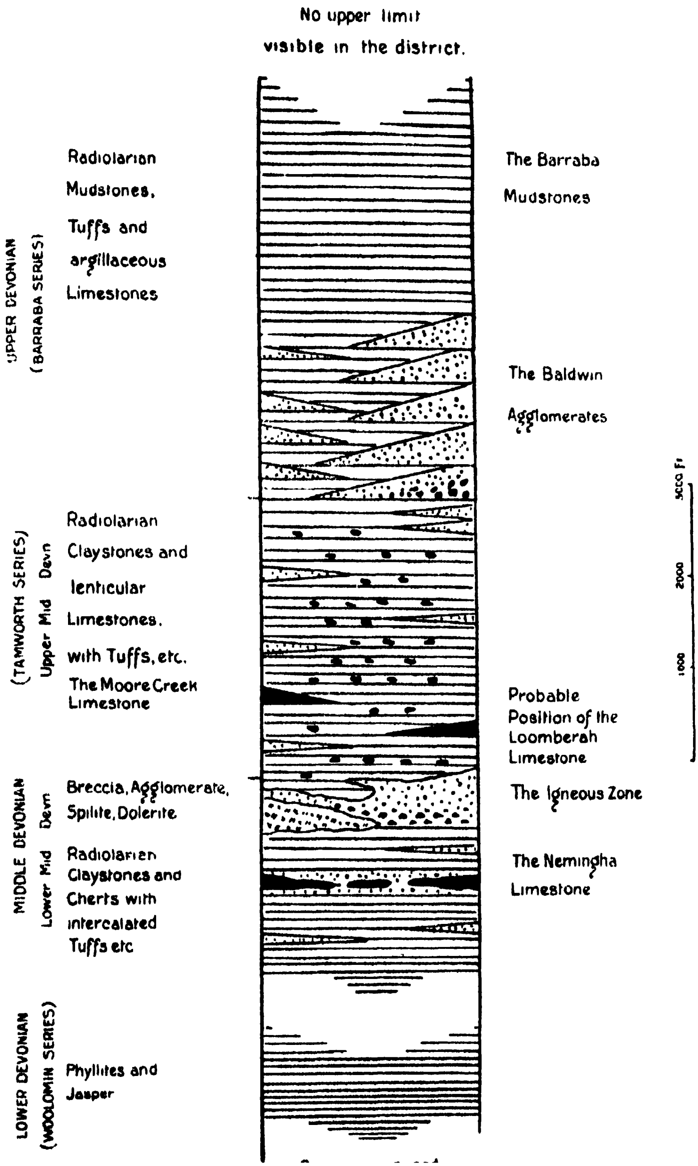
fine grey rocks of quartzitic appearance, and greener masses, like altered tuffs and greywackes. Higher up, the quartzitic rock becomes more coarsely granular, and contains scattered crystals of felspar, and it is intersected by an occasional vein of jasper. The microscope reveals that the greenish rocks are highly altered silicified and strained tuffs, while the rocks of a quartzitic appearance are chiefly much crushed and metamorphosed keratophyres of a type that finds no analogy among the rocks of the Middle Devonian Series. All the rocks of this hill seemed to have been recrystallised under the metamorphosing influence of the adjacent granite. The details of the petrography are given below.

About a quarter of a mile south of this, is a large mass of tuff-breccia, lying east of the serpentine, but very closely resembling some of that to the west in the Middle Devonian Series.

The purely sedimentary rocks, in addition to the banded cherts, are jaspers, phyllites, rarely so fissile as slates, and generally pale brown or green in colour. These pass into jaspers, or are veined or interstratified with jasper. There is no exact analogy for these rocks among those of the higher series, unless they are derived from the Upper Devonian mudstones, which seems unlikely. It is these rocks, if any, that are to be considered of Lower Devonian age. It is quite impossible to estimate their thickness.

### 2. *The Tamworth Series of Middle Devonian age.*

The main interest in the stratigraphical portion of this paper, lies in this division of the geological record. We cannot yet, however, be certain as to the relative thicknesses of the subdivisions that have been adopted. The zones proposed depend partly on their lithological character, partly on the fauna of their associated limestones. In place of the single horizon of limestone formerly recognised, three are now believed to be developed, though the position of one of them is scarcely known at present. The three, in probable chronological order, are as follows: the Nemingha Limestone, the Loomberah Limestone, and the Moore Creek Limestone.




**Text-fig. 1.—Columnar Section of the Devonian Series in the Tamworth District.**

To see the succession most clearly, we must commence at the anticline in the valley of the Seven Mile Creek, and follow west along the line of section described by Messrs. David and Pittman. The lowest beds are radiolarian claystones, in places more or less cherty, and associated with several bands of tuff. Above them comes a narrow band of limestone, bent sharply by the anticline. It is not more than fifty or a hundred feet thick, and is so altered by the contact-effect of the adjacent granite, that its fossil-content is scarcely recognisable. The presence of *Favosites*, *Alveolites*, *Diphyphyllum*, and a pentameroid shell, was noted by the previous observers. For reasons which will appear subsequently, this limestone is considered to be on the same horizon as that which we have termed the Nemingha limestone. It is associated with more or less tuffaceous material. Above this commence the great thicknesses of radiolarian cherty claystones with lenticular, interbedded, radiolarian limestones, and vast quantities of pyroclastic material, that form the bulk of the Middle Devonian Series. Not far above the limestone, however, is frequently found a finegrained, grey, quartzitic rock, and, above this, is the greatest and most persistent of the zones of igneous rock. In this portion of the district, the Igneous Zone is composed chiefly of pyroclastic rock, though, elsewhere on this horizon, large masses of spilite and spilite-porphyry are developed. For convenience of reference, all the Tamworth Series up to and including the Igneous Zone are here classed as the Lower Middle Devonian Series.

The Upper Middle Devonian Series, above the Igneous Zone, consists of a great thickness of cherty radiolarian claystone, and banded cherts, with lenticular masses of radiolarian limestone, interstratified with pyroclastic rocks. This extends uninterruptedly up to the base of the Baldwin Agglomerates in the Upper Devonian Series. If we anticipate the discussion of the distribution of this series, however, it will be seen that, on two horizons in this sequence, limestone might occur. Northwards of Messrs. David and Pittman's line of section, the large mass of limestone on Moore Creek will be found to lie among radiolarian cherts above the Igneous Zone, but far below the Baldwin

Agglomerates. The horizon so determined is taken as the Moore Creek limestone horizon. South of the limits of the present map, in the Parish of Loomberah, is a richly fossiliferous limestone also occurring a short distance above the Igneous Zone, but differing in character from the Moore Creek limestone. This is accepted as marking another horizon, that of the Loomberah limestone. Very little is known of it as yet, and its relation to the Moore Creek limestone is undetermined. The presence of this limestone in the area covered by the present map is not fully proved, though two unfossiliferous masses in the south-eastern corner probably belong to it.

*Fossils of the Tamworth Series.*—The fauna of the Nemingha and Moore Creek limestones is tabulated below :—

| NEMINGHA LIMESTONE. | MOORE CREEK LIMESTONE. |
|---|---|
| Lower Middle Devonian. | Upper Middle Devonian. |
| | *Lithistid Sponges (several undetermined species). |
| *Favosites gothlandica* var. *moonbiensis*. | *Favosites gothlandica*. |
| | *F. basaltica* var. *salebrosa*. |
| *F. multitabulata*. | *F. squamulifera*. |
| *F. pittmani*. | **F.* sp., cf. *pittmani*. |
| *F.* sp., cf. *forbesi*. | |
| **F.* sp.nov. α. | *F. crummeri*. |
| **F.* sp.nov. β. | **F. reticulata*. |
| | **F.* sp.nov. γ. |
| | **F.* sp.nov. δ. |
| **Stromatopora* sp. | *Stromatopora* sp. |
| **Stromatoporella*(?) sp. | *Stromatoporella*(?) sp. |
| **Diphyphyllum porteri*. | *Diphyphyllum porteri*. |
| | **D. giganteum*. |
| | *D. robustum*. |
| | **D.* sp.nov. |
| | *Spongophyllum giganteum*. |

| | |
|---|---|
| *_Tryplasma_, sp.† | |
| *_Sanidophyllum davidis._ | _Sanidophyllum davidis._ |
| *_Alveolites_ sp. | _Alveolites subæqualis._ |
| | _Litophyllum konincki._ |
| | *_L._ sp.nov. |
| | _Actinocystis cornu-bovis._ |
| *_Cyathophyllum_, sp.nov. | _Cyathophyllum obtortum._ |
| | _Microplasma parallelum._ |
| *_Heliolites porosa._ | _Heliolites porosa._ |
| *_H._ sp., cf. _interstincta._ | |
| *_Syringopora_ sp. | _Syringopora auloporoides._ |
| | _S. porteri._ |
| *Monticuliporoid. | |
| Crinoid-stem ossicles. | Crinoid-stem ossicles. |
| Pentameroid brachiopod. | *_Pentamerus_ sp., cf. _knightii_ |
| *_Athyris_ sp. | |
| *_Zygospira_ sp. | |
| *_Cœlospira_(?) sp. | |
| | *_Atrypa_ sp. |
| | *_Aviculopecten_(?) sp. |
| *_Cyclonema_ sp. | |
| Indeterminate gasteropod, four inches long. | * _Vetotuba_ sp. |

In drawing up this table, the writer has had the privilege of using the collections of Mr. T. England, B.A., of Tamworth, and Mr. S. M. Tout, to whom he is greatly indebted, and, in these as well as in his own, occur several forms, kindly determined by Mr. W. S. Dun, which do not appear in the earlier lists. These have been marked with an asterisk.

It may be advisable to call attention to the points of difference in the two faunas. The Nemingha limestone is characterised by the abundance of _Favosites multitabulata_ and of _F. pittmani._

† Mr. Etheridge states that this species is very like _T. lonsdalia_ var. _scalariformis_, which he has already recorded from the Nemingha Limestone (Memoirs Geol. Survey of N.S.W. Palæontological Series, No. 13, p. 31). He is preparing a description of this form, with others collected from the Devonian rocks of the Great Serpentine-Belt.

*Stromatopora* is fairly common, and a form of *Heliolites*, that is apparently not *porosa*, is occasionally present, while a certain species of *Tryplasma* is rather common The other forms are of less stratigraphical importance, and *Sanidophyllum*, though occasionally present, is very rare. The Moore Creek limestone is characterised by the abundance of *Sanidophyllum davidis*, *Spongophyllum giganteum*, *Actinocystis cornu-bovis*, *Syringopora auloporoides*, *Litophyllum konincki*, and *Heliolites porosa*, the last often forming very large masses. All these forms are rare or not developed in the lower limestone.

The study, by Dr. Hinde, of the radiolaria of the Middle Devonian Series included the description of fifty-three new forms(**10**); others still await description.

The Upper Middle Devonian claystones, but not, so far as is at present known, the Lower Middle Devonian, contain numerous casts of *Lepidodendron australe*, both in its normal form, and in the *Knorria*-condition. It may be found especially in Long Gully, and also in Loder's Gully, but is not so abundant here as it is in the Upper Devonian rocks.

*Distribution of the Lower Middle Devonian Rocks.*—Taking the limestone (associated with tuff), the cherty and quartzitic rocks, and the Igneous Zone as the characteristic rock-types of the Lower Middle Devonian Series, let us trace them northwards and southwards from the above-mentioned line of section, to ascertain the structure of our area. The northward-pointing arch of the limestone in the anticline in Seven Mile Creek, is met by another pointing southwards, and very sharply bent. Its two branches are close together, and, traced northwards, appear at intervals all the way to Moore Creek. They form narrow, lenticular patches generally closely associated with pyroclastic rocks, and frequently completely surrounded by them, or appearing merely as large or small inclusions of limestone in a mass of pyroclastic rock. This passage of a band of limestone into an igneous breccia containing fragments of limestone is a constant feature of this horizon throughout the whole of the Serpentine-Belt, as was pointed out in earlier papers, and is particularly well exhibited in the Nundle District(**15**). It is also

seen in the Middle Devonian Series of the Dillenburg district, in Germany(18), in the Carboniferous formation of the Isle of Man(19, Vol. ii., p.25), and elsewhere. As will appear later (p.574), the same structure is developed in the Ordovician Series of the West of Ireland, in association with a varied group of rocks, some of which are remarkably like those of the Middle Devonian formation of New South Wales(20).

The various outcrops of limestone do not join up regularly into two lines continuing the branches of the Seven Mile Creek anticline. Sometimes three lines are present, sometimes only one. The grey quartzite appears here and there in small amount. The occurrences of pyroclastic rocks, which are indicated on the map in a generalised manner only, are equally irregular in their development, though all are approximately parallel. The dip of the rocks is very steep (60°-85° to the N.E. or E.N.E.), and the exposures in the steep easterly-flowing gullies show much shearing and shattering. All these features indicate that the Lower Middle Devonian Series in the narrow zone along the margin of the granite-massif, is affected by much strike-faulting and repetition, as well as simple folding. Intrusive into those rocks are some small basic sills of porphyrite; that occurring in the south-western side of portion 158, Woolomol, has phenocrysts of basic labradorite, and has suffered very little from the metamorphosing effect of the granite when compared with the pyroclastic rocks.

We return to Seven Mile Creek, and now trace the Lower Middle Devonian Series to the south-east. The continuous band of limestone ceases by the Loder's Gully track to Tamworth, but is represented beyond this by small isolated lenticular masses which run round the wide open valley of Seven Mile Creek, and, swinging round in a rough semicircle, are found again in the small ridge west of Tintinhull railway-platform.

Here the limestone is again associated with a small amount of pyroclastic matter. Below the limestone, the regular sequence of outcrops of claystones and tuffs curves in a similar manner, dipping to the south-west, south, and finally to the south-east. To the east of the anticlinal axis, they follow parallel to the boundary of the granite, and dip steeply to the north-east and

north. They have here undergone considerable metamorphism, which has increased their resistance to erosion, so that they form a ridge between the granite and the valley of Seven Mile Creek. Thus this arching of the strata is not a simple anticline, but an ovoid pericline. The discontinuity of some of the beds suggests that some faulting is also present, but this cannot be proved An apparent thickness of about a thousand feet of strata is exposed below the limestone.

Above the limestone are, here and there, masses of the finegrained quartzitic rock, and a thickness (at Tintinhull) of approximately four hundred feet of claystones with some radiolarian limestones, and a small amount of pyroclastic material. Elsewhere this zone is of greater thickness. The angle of dip at times is quite small; one has been measured as low as 5° to the S.S.W. Above these comes the great mass of pyroclastic rock, which makes up the Igneous Zone. It is not more than one hundred feet thick at the head of Loder's Gully, but increases in width to the south, the outcrop being more than a quarter of a mile across. The very indented outline of this mass is partly the result of an interdigitation of claystones and tuffs, but may also indicate some repetition of beds by strike-faulting. The wide zone of pyroclastic rock forms the crest of the ridge between Loder's Gully and Seven Mile Creek, and, swinging round in conformity with the limestone, and becoming more coarse in grainsize as it turns, it is partly replaced by massive igneous rock (porphyritic spilite) about half a mile south-west of Tintinhull railway-platform. The line of junction of the massive and pyroclastic rock is not anywhere visible; indeed, there seems to be a passage between the two. On either side of the massive rocks is a varying amount of pyroclastic material, usually finegrained. It varies somewhat in character; sometimes it has a granular base with a grainsize of about 0·5mm., but more usually the base is aphanitic and more or less vesicular. Except for the presence of vesicles, the rocks are very similar to those which occur in the Eastern Series, in the Nundle district(17, p.146). With these is a finegrained, apparently massive rock, which microscopical study shows to be pyroclastic. The matrix of the

rock is the same as that of the more finely granular spilite-porphyrites, and contains some well shaped phenocrysts, but the majority of the larger grains, which are only 0·2 mm. in diameter, are fragments of albite-crystals. There are also fragments of a pilotaxitic, felspathic rock rather poor in ferromagnesian minerals (keratophyre), as well as others richer in these minerals (spilite). This rock is one of the most finely granular of the rocks which seem to have a character intermediate between that of massive and pyroclastic types.

The petrological character of this complex must be our guide to further unravelling the stratigraphy of the Lower Middle Devonian Series. The wide alluviated valley of the Cockburn River obscures any direct linking of the formations across the stream, but the exact equivalent of the Tintinhull spilite is found to form the small hill in portion 48, Parish of Nemingha, by Pullman's farm. The hill, which is probably divided by a fault, consists of two masses of porphyritic spilite, separated by a band of pyroclastic material. The upper mass shows some indefinite signs of ellipsoidal partings. The dip of the associated beds (W. 10° N. at 40°) shows that a syncline exists below the river, and that this spilite-mass may well be the same band as that occurring at Tintinhull. As this rock was fairly free from epidote, it was chosen for analysis, and proves to be thoroughly albitic (see No. 1130, p. 602).

Eastward of this hill, are phyllitic claystones and quartzitic rocks, resembling those that lie between the Igneous Zone and the limestone. But, in place of the limestone, the igneous band appears again, southwards from portions 66/148; its reappearance is probably due to a fault, rather than to anticlinal folding, as the dip is to the west also. The igneous series here consists chiefly of pyroclastic material, but on its eastern side is a mass of porphyritic spilite like that at Tintinhull. The thick pyroclastic series extends southwards for over two miles, and forms the greater part of the hill, which we will term West Gap Hill (see Topographical Map, Pl. xlix.). The indented outline of the igneous rock, and its repetition, probably indicate the presence of a group of strike-faults here. The nature of the rock varies

to a certain extent; parts of it are richer than the remainder in fragments of keratophyre, and very coarse-grained agglomeratic rock, part of which is very ferruginous, occurs immediately west of the Gap. Associated with these is a red finely granular to aphanitic tuff, that appears quite massive in hand-specimens, save for the presence of a few larger fragments. The associated cherts are interbedded with tuffaceous material, and the beautiful instance of an intrusive tuff, which is discussed below, came from this spot. See Text-fig.5 and Plate liii., fig.10.

The mass of tuffs and breccias is invaded by a small intrusion of dolerite in the southern end of the hill. On the northern end of the hill, a spur runs towards the forking of the roads. This consists very largely of banded claystones and grey quartzite like that at Tintinhull. At the base of the hill, and following up the Gap Road, is a series of limestone-outcrops. One of these, the large mass exposed in portion 163, was the source of the fossils described by Mr. Etheridge from "Beedle's Freehold"(11). The limestones north of the Gap are usually grey or white, and are more or less associated with tuffaceous material (see p.575). South of the Gap, the limestone has a reddish colour, doubtless connected with the presence of ferriferous keratophyres. (See chemical analyses, p.611). A small quarry was opened in these to exploit the Nemingha crinoidal marble; several varieties of ornamental stone were obtained, of which beautiful examples may be seen in the museums of Sydney, particularly the Technological Museum. [See the coloured illustration in(13)]. The stone has not yet been put to much use commercially. This is the typical occurrence of the Nemingha horizon, and the stratigraphical details mentioned above are the grounds upon which it is correlated with the limestone of Seven Mile Creek. For some distance south of here, as will appear more particularly in a later communication, the limestone is directly associated with massive, brecciated, ferruginous rocks, keratophyres and the like, and is separated from the Igneous Zone by a considerable thickness of claystones and cherts. The close approximation of the limestone and the Igneous Zone in the Gap must be due to faulting. A small fault is visible by the limestone-quarry, marked by

a breccia of red and white limestone. The fauna of this limestone has been tabulated above.

Directly east of the Nemingha limestone zone is the largest mass of porphyritic spilite that occurs in the district; it forms the ridge termed East Gap Hill. This, also, must be correlated with the Tintinhull spilite. The southern end of the hill consists of pyroclastic rocks, with the seemingly massive, ferruginous keratophyre-breccia like that on West Gap Hill. This passes without any junction-line into a very vesicular porphyrite, and, on the top of the ridge, into a slightly vesicular porphyrite, with phenocrysts of albite, and a subvariolitic groundmass of felspar, uralite, and chlorite (see Text-fig.4, p.565). Except for the greater abundance of the felspar, the mineral-composition is exactly that of the spilites of Tintinhull, and there is little reason to doubt that this is but a thicker, and more coarsely crystalline portion of the same mass as the other rocks, brought by faulting or folding into its present position. The northern end of East Gap Hill is occupied by a mass of rather decomposed dolerite, which invades the spilite-porphyrite, and extends nearly to the Cockburn River. This intrusion is partly albitic, but the greater portion contains andesine, or labradorite. We will return subsequently to discuss the manner of origin of the igneous rocks of East Gap Hill (p.564).

Eastwards of this occurrence of the Igneous Zone, we can not determine the tectonic structure with any degree of probability. No further zones of igneous rock occur, which resemble either the spilite-porphyrite, or the ferruginous keratophyre-breccias described above. Moreover, the angles of dip of the strata, when observable (and this is but seldom), afford no help, being usually almost vertical. However, the large mass of limestone in portion 91 and the eastern end of 88, though too altered for the preservation of fossils, resembles that of the horizon last described, and may be supposed to be the limestone that should occur below the spilite-porphyrite of the Igneous Zone on East Gap Hill. Isolated lenticles of limestone occur on the same horizon in portion 168, and are included in a mass of tuff-breccia in portion 207, while a possible continuation of this zone is shown

by the small patch of limestone in the keratophyres of portion 175 (see p.572). The lenticles of limestone that lie about a quarter of a mile east of this line, in portions 180 and 216, are probably on the horizon of the Loomberah limestone. They are white, crystalline rocks, free from pyroclastic impurities, and all trace of fossils has been lost. East again of these, there is another line of doleritic intrusions, lying along the western side of Spring Creek. These may perhaps be correlated with the Igneous Zone. If so, we may class with the Nemingha horizon the series of limestones that occur in the creek-valley, and commence to the north with the large mass of metamorphosed limestone, in portions 88, 91, and 118, which is exactly like that described above. This is followed to the south by a series of small lenses of limestone, generally intimately associated with pyroclastic rocks, occurring in portions 126, 216, and 153. At the southern edge of the map in portion 121, is a large lenticular mass of white crystalline limestone, quite free from traces of fossils, about 400 yards long and 60 yards wide. This is probably on the same horizon as the limestone that occurred on the boundary of portions 180 and 216, and may tentatively be classed with the Loomberah limestone. The stratigraphy of the southern end of the area mapped is quite indefinite. To complete the tracing of the structure-lines, as far as is possible, one may note that, east of Spring Creek, in portions 113, 119, and 123, is a mass of highly altered dolerite, and other basic rocks, which may represent still another repetition of the Igneous Zone. Further repetitions of the rocks of the Lower Middle Devonian Series occur, as has been noted above, among the rocks of the Woolomin Series, and, together with them, make up the Eastern Series, which lies east of the Serpentine-Belt.

*Distribution of the Upper Middle Devonian Rocks.*—This series has been defined as that extending from the Igneous Zone, which closes the Lower Middle Devonian, upwards to the Baldwin Agglomerates. It includes the Loomberah and Moore Creek limestones, but, as these occur at opposite ends of the area mapped, their relation to one another is not known. Apart

from these limestones, the Upper Middle Devonian Series is a monotonous succession of radiolarian claystones and cherts, with lenticular intercalations of radiolarian limestone, frequent casts of *Lepidodendron australe*, preserved in the radiolarian rock, with abundant masses of interstratified and intrusive pyroclastic rock, which show spheroidal weathering particularly well in the railway-cuttings. The interstratified tuffs may also show casts of *Lepidodendron* or contain radiolaria.

The limestones which occur at the extreme south-eastern end of the map, which, also, have been correlated with the Loomberah limestone, and the cherts associated with them, probably belong to this series; but the southernmost definite instance of its occurrence is afforded by the rocks that form the western slopes of West Gap Hill. The zone occupied by the series then follows the flexions of the Lower Middle Devonian rocks, bending with syncline and anticline, passes up Loder's Gully, and forms the hills by the Tamworth trigonometrical station, and the western slopes of the ridge extending to Moore Creek. Here the limestone occurs in abundance, and is the type-occurrence of the Moore Creek limestone. Only one band is present, but, as shown on the map and sections, (Plates l.-li.) it is much folded, faulted, and repeated. The previous writers have stated that the limestone reaches a thickness of 1000 feet, but the writer has not seen any section showing a thickness of limestone which one can with safety assume to be more than 450 feet. The evidence available is too poor to admit of a more definite statement than this. The masses of limestone are lenticular in shape, and thin out, and disappear about a mile south of the creek. They are directly underlain and overlain by radiolarian cherts.

The greater part of the Upper Middle Devonian Series is repeated by the fault that runs along Spring Creek through the Tamworth Common, which fault was discovered by Messrs. David and Pittman(9). This is not a simple fault, however, but a fault-zone or plexus. In several places, the faults are made very obvious by the fact that the adjacent rocks have been strongly silicified or even metasomatically replaced by quartz, owing to the action of siliceous solutions rising in the fault-fissures. The

lowest beds made visible by the fault are the clayshales and cherts, immediately underlying the limestone, which is obviously of the same character as the Moore Creek limestone, is silicified in the same way, contains precisely similar fossils, and is associated with similar rocks. The silicification of the limestone is very irregularly distributed; portions of some fossils may be replaced by silica, a sort of beekite, while the remainder may be pure calcite. Again, long or short, irregular, siliceous bands occur quite apart from the fossils, or, again, the fossils may be found to have merely an outer skin of silicification. The limestones on Spring Creek are divided up into small masses, partly, no doubt, by the plexus of faults (sometimes marked by fault-breccias), but also owing to the fact that they were originally formed as small lenticles, or masses which interdigitated with the claystones. This is clearly seen in a small cutting below the Corporation's stone-crushing mill (see Text-fig.2). These claystones

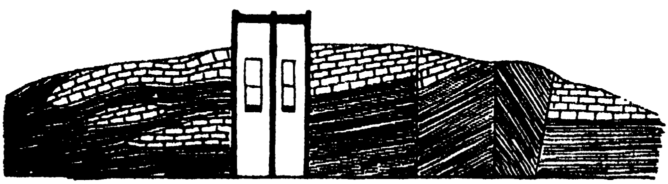


Fig.2.—Lenticular coral-limestone and radiolarian claystone of the Moore Creek horizon, exposed in road-cutting by the rock crushing plant on Spring Creek, Tamworth Common.

are of the normal siliceous type; they are not calcareous mudstones, such as one might expect if the coral-reef, that is now limestone, had risen to the surface of the sea, and had come under the shattering influence of the waves. In this way, the Tamworth and Moore Creek limestones differ from the Devonian limestones of Ohio, that were described by Grabau, and from other limestones of a like character(21).

Neither the Moore Creek nor the Tamworth limestone-occurrences are closely associated with any igneous rock, though a short distance above the limestone at Tamworth are a few thin bands of pyroclastic rock, and some very narrow layers of felspathic tuff, which show the clearest evidence of their intrusive

character. Little veins, that break across the stratification of the claystones, project outwards from the otherwise apparently interbedded tuff. It was first pointed out to the writer by Mr. Aurousseau, B.Sc., that one of the bands of igneous rock about a yard in width, though no different to the naked eye from the normal fine-grained tuff, was really a massive and thoroughly albitised spilitic dolerite. Though a number of other fine-grained igneous rocks in the Upper Middle Devonian series have since been subjected to microscopic examination, this is the only massive rock yet found in that series. It occurs in the road-metal-quarry, at the southern end of the ridge beside the creek. In this quarry, and in that adjacent to it, are the most accessible examples of the interbedded lenticular radiolarian limestones. They occur up to six feet in length, and nearly two feet in width, but the majority are smaller than this. Some sign may at times be seen of a structure that has been most clearly observed in a limestone-lens at Nundle, namely, that the same lines of stratification as are in the adjacent mudstone continue right through the limestone, but are much further apart here than in the claystones. The bedding-planes of the claystones, therefore, appear to bend inwards at either end of the limestone-lens, and thus to follow its outline (see Text-fig.3) Presumably the lens was

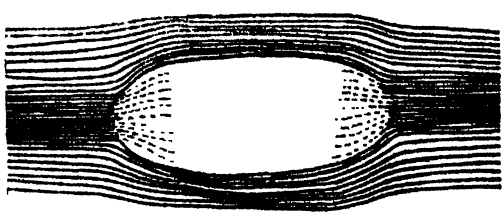


Fig.3.—Lenticle of Radiolarian Limestone.

formed by segregation of lime in the soft unconsolidated muds, which have subsequently been much more closely compacted by pressure of overlying sediment, etc., than the solid lens which had formed in them.

Below the limestone at the southern end of its outcrop, is a small anticline noted by the previous authors. It seems, how-

ever, to be most probably only the dragged-down edge of the strata adjacent to the fault.

West of this limestone-horizon, is the monotonous series of claystones and lenticular radiolarian limestones extending to the foot of the ridge between the Moore Creek and Manilla roads, which ridge is composed of the Baldwin agglomerates. For this reason, the claystones must be correlated with the cherty rocks that lie below the agglomerates, at the mouth of Long Gully, and would, therefore, indicate that a variation of the degree of silicification may occur when a series is traced along the direction of the strike. Such variation is, indeed, very common in the rocks of the Upper Middle Devonian Series, and often causes uncertainty as to the proper correlation of isolated occurrences.

The repetition of the Upper Middle Devonian Series is found again on Moore Creek, where the limestone itself is repeated in the small hill in portions 41, 42, 43 of the Parish of Woolomol, which is the top of an anticline. This limestone is exactly similar in all its features to the other large mass of limestone on the southern side of Moore Creek, and must clearly be correlated with it. Unfortunately, the whole of the central part of the Parish of Woolomol is covered with drift, so that the details of the stratigraphy are hidden. It may be safely assumed, however, that a fault separates the limestones in portions 41-43 from the pyroclastic rocks immediately to the west of them, as the intervening distance is far too small to permit of the unhindered development of that part of the Upper Middle Devonian Series which lies between the horizon of the Moore Creek limestone and that of the Baldwin Agglomerates.

The geological sequence is very indefinite south of the Peel River owing to the want of clear exposures. The Baldwin Agglomerates may be recognised on the hill east of Goonoo Goonoo Creek, and all the country east of these is made up of slightly silicified and soft radiolarian claystone, with lenticular limestones and pyroclastic intercalations. These most probably belong to the Upper Middle Devonian Series, but it has not been possible yet to link up definite bands of pyroclastic rock with similar bands north of the river. The alluvium of the Peel

River seems to hide some line of faulting or discontinuity, in the lithological character of the country.

*Igneous Rocks of the Middle Devonian Series.*

In the foregoing, the more important occurrences of igneous rock have been briefly mentioned, but no attempt has been made to discuss the conditions attending their development. This we will now endeavour to do. The most varied and instructive area is that of East Gap Hill, of which a sketch map is given (Text-fig.4). Passing from north to south, one has:—

1. Massive dolerite.
2. Porphyritic spilite.
3. Spilite only slightly porphyritic.
4. Vesicular spilite.
5. Passage-rocks between vesicular spilite and breccia.
6. Breccia or agglomerate.

There exists a very clearly marked boundary between the first two, but a gradual passage between all the other members. There can be no doubt that the dolerite is intrusive into the cherts, and also into the spilites. The relations of the spilites are not so clear. Along the eastern, and presumably lower side of the igneous mass, the boundary of the spilite seems to transgress the bedding of the cherts, and is rather irregular, though it is not clear whether it should be considered transgressively intrusive into consolidated cherts, or merely into the semi-liquid unconsolidated sediments on the sea-floor. This point was discussed in another connection in the previous paper(17). The igneous rock along this eastern (lower) side is locally brecciated, and such breccias, often with the relations of intrusion-breccias, may contain very vesicular patches. These vesicular patches of breccia may grade into massive vesicular rock and thence into the dense solid rock of the main mass of spilite. This seems to indicate that the igneous mass was intruded into sediments that were at least partially consolidated. From this edge of the mass, there projects a narrow tongue of solid spilite a short distance to the east, but it is not clear that this is a feeding dyke; it may be merely a portion of the mass

displaced between two faults. The main mass of the intrusion, occurring on the top of the ridge, contains large and abundant phenocrysts of albite. These decrease in size as the rock is traced to the south, and the rock at the same time becomes more

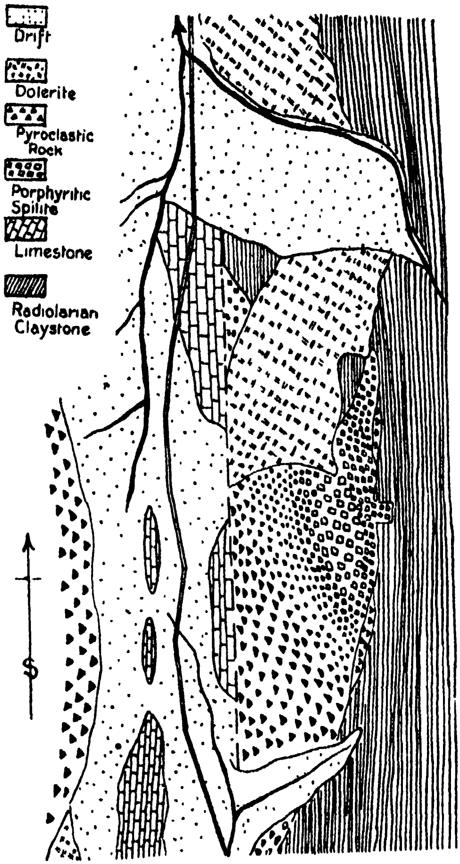



Fig. 4.—Sketch Map of the East Gap Hill Complex.

and more vesicular; it begins to take on a reddish tint: fragments make their appearance, and imperceptibly one passes into breccias and agglomerates, composed of more or less ferruginous keratophyres or spilites, in which the ferromagnesian minerals have been destroyed, leaving only a red staining of hæmatite. These

are described in detail in a later portion of this paper. The relation of these breccias to the overlying sediments is obscured by drift. The Nemingha limestones follow immediately west of the hill, but are believed to be separated from the igneous rocks of East Gap Hill by faulting. They show no sign of contact-alteration, and there is other evidence of the presence of one or more strike-faults running through the Gap itself, *e.g.*, in the presence of a fault and a band of fault-breccia traversing the limestone in the "red marble" quarry in Portion 134. The problem is rendered more complex by the presence of tuffs in intimate association with the limestone, which often cannot be distinguished from those that occur in the Igneous Zone and lie stratigraphically several hundred feet above the limestone.

The igneous rocks of West Gap Hill are almost entirely fragmental. They are quite similar to those of East Gap Hill, of which they are, it is believed, the faulted equivalent They are sometimes very coarsely granular, the fragments being several inches in length, and include cherts and limestones, as well as igneous rocks. The cherts form particularly large angular pieces. This mass of fragmental rock is invaded by massive albite-dolerite, which occurs on the southern end of the hill. Various exposures show the relation of the pyroclastic and sedimentary rocks to one another, and the frequently intrusive nature of the former can be thoroughly substantiated. No single specimen, however, is more instructive than that shown in Text-fig.5, and Plate liii., fig.10. This consists of green banded chert, with intercalated bands of purplish pyroclastic material, which have a sharply marked boundary on the one side against the chert, and a gradual passage between the two rocks on the other. This is clearly due to successive small eruptions of tuff, which filled the sea with fine ash, that deposited in layers at first sharply distinct from the clay on to which it fell, but faded away gradually upwards, as the slowly settling remnants of the ashy material became more and more mixed with the normal sediment (radiolarian clay). Intrusive into this banded rock, and cutting across its bedding-plane, is a tongue of breccia, of the same composition as the interbedded tuff, though of larger grain-size.

The writer has not been able to find an account of associations of pyroclastic rock and sediment exactly similar to those of the

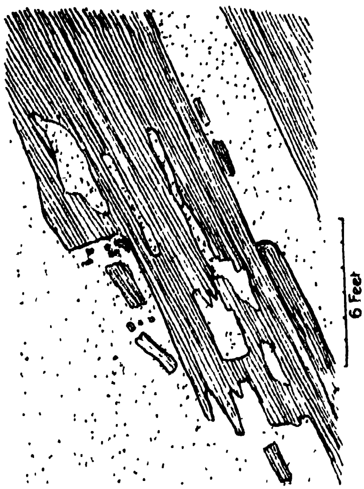



Fig.6.


Fig 8

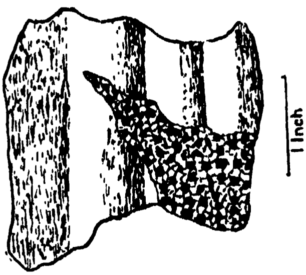



Fig.5.


Fig 7.

Fig. 5.—Interbedded and intrusive pyroclastic rock, West Gap Hill.
Figs 6-7.—Intrusive pyroclastic rocks, Railway-cutting, Nemingha.
Fig. 8.—"Eddy-bedding" in claystone and tuff, Railway-cutting, Nemingha.

Tamworth District,* and has been led to adopt tentatively a rather speculative explanation of the features present. A fact

* See Postscript to this paper.

that is difficult to understand, is the almost complete absence of glassy matter among the pyroclastic rocks. As will be seen, they consist (*a*) of fragments of rocks passed through by the ascending igneous material, chert, limestone, etc., and (*b*) fragments, isolated crystals, and portions of crystals from medium- and fine-grained rocks of the dolerite-spilite-keratophyre series. In the case of the "intrusive tuffs," the rock consists largely of grains of minutely crystalline trachytic keratophyre, which recall the constituent granules in the brecciated keratophyre of Hyde's Creek(17). Though the ascending magma must have been rapidly chilled by the wet sediments, it must also have been charged with a considerable amount of water, from which it could not free itself. There would thus be a mineraliser constantly present during the period of consolidation, which might partly account for the advanced crystallisation, frequently very minute, of the rock. Also, any glass that formed in these conditions would probably be rapidly devitrified, and, indeed, much of the crypto-crystalline grains may be devitrified glass. The movement of the molten material below would break up the crust as it consolidated, and it would also be shattered by the strains produced in the necessarily rapid variations in temperature, so that, above the level where the crystallisation took place, the comminuted igneous material would move forward in the form of a watery slurry or mud. This mud would escape from the vent in which it rose, by the path of least resistance, which, under a considerable overburden of silt and sea-water, might sometimes be by intrusive injection into the surrounding partially consolidated sediments, at other times, by breaking through and discharging into the sea. This would doubtless be accompanied by more or less energetic convulsions. In the latter case, the igneous material would settle down on the sea-floor, as a band of tuff, either pure or mixed with normal marine sediment. Hence might arise the well ascertained fact, that it is often quite impossible, by purely petrographic means, to distinguish between a sedimentary and an intrusive pyroclastic rock in this district.

An objection to this explanation, which cannot yet be satisfactorily answered, is the uncertainty that the greatest depth

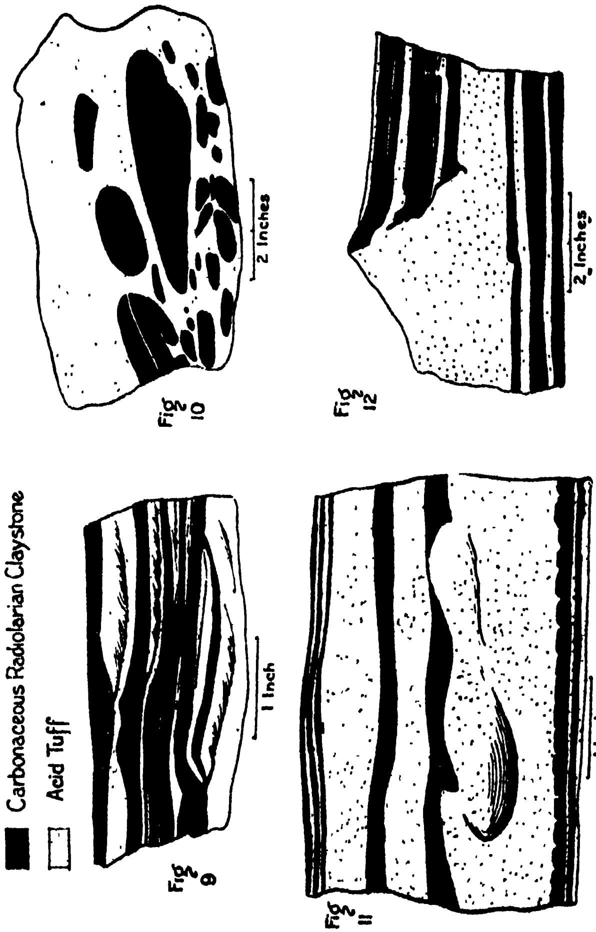
which we can assume for the sea in which the sediments were deposited, would give an overburden of water and silt sufficient to act in the manner indicated. There would also need to be a rather nice adjustment of the rate of protrusion of the magma. If it were greater than that necessary for the development of intrusive tuffs, masses of lava would invade the sediments, and different features would result.

It seems possible to explain thus the passage between the massive and brecciated igneous rocks seen on East Gap Hill, and also, though not so clearly, on the ridge north-west of Tintinhull Railway-platform. The upper portion of a mass of lava intrusive into, or flowing through wet, semi-consolidated sediment, would naturally be especially liable to brecciation. Again, the abundant opportunity offered by such brecciation for the passage of solutions would be exceptionally favourable for the destruction of the ferromagnesian minerals, and the oxidation of their iron-content to magnetite and hæmatite. To some such processes, the peculiar features of the red breccias and agglomerates of East and West Gap Hills may owe their origin.

The sections exposed in the railway-cuttings between Tamworth and Tintinhull, particularly those immediately east of Nemingha, afford further examples of this phenomenon, as will be seen from the features illustrated in the figures herewith. (Text-figs.6, 7, 10, 12).* An intrusion of pyroclastic material into partially consolidated sediment might be expected frequently to transgress the bedding-planes of the sediments, to crumple them, and to include numerous crumpled or uncrumpled fragments of them. The exposures illustrated clearly exhibit these features, and further indubitable evidence of intrusion is afforded by the microscopical preparation illustrated in Plate liii., fig.6. The original of this is in the collection of the Geological Survey of New South Wales (No.1190), and was one of the slides used by Messrs. Pittman and David in the preparation of their work. The writer is indebted to these gentlemen for permission to

* Compare with these illustrations the figure given by Sir A. Geikie of a breccia invading a slate (19, Vol. ii., p.50, fig.198). The explanation of this feature is not, however, applicable to the Tamworth rocks.

illustrate it here. Again, lateral injections and explosions within unconsolidated sediments of the character we are considering, would be accompanied by more or less sliding of the lamellæ over one another, which would result in the tearing up




Figs. 9 and 11.—Effect of lateral thrust on unconsolidated, interlaminated acid tuff and carbonaceous claystone, Railway-cutting, Nemingha.
Fig. 10.—Intrusive tuff with rounded inclusions of carbonaceous claystone.
Fig. 12.—Tuff intrusive into carbonaceous claystone, Railway-cutting, Nemingha.

of the lamellæ, and their injection into one another. This is particularly well shown when black carbonaceous layers alternate with white tuff. A specimen of this is illustrated by Text-figure 11. Again, the small convulsions caused by the ejection

of material, would occasion some oscillatory movement in the water on the sea-floor, which might result in a sedimentary structure resembling current-bedding in the mass of the silt lifted and redeposited at each convulsion. The specimens illustrated by Text-figs. 8 and 9 may perhaps be an example of this. We may compare with figure 8, the illustration of false bedding in chert seen by Clements in the Pre-Cambrian rocks of Michigan, which are also associated with tuffs (**22**, Plate xxvii.). It must be noted, however, that ripple-markings were seen among these rocks by the previous authors(**9**). According to Hunt(**23**), these do not necessarily indicate a very shallow sea. They may form at considerable depths, as much as 188 metres in one instance cited. It is not clear to the writer whether the features seen in Text-fig.8 are the result of a general rippling oscillation or eddying produced as suggested above The extremely local character of the phenomena may indicate that the latter alternative is the more probable.

Intrusions of pyroclastic rock into more consolidated chert would require more energetic explosions than those described above, and would result in much shattering. Rocks which illustrate this are very frequent along the west side of the serpentine in Spring Gully, and have been found in the Nundle District(**17**, pp.166-7.* See also p.575).

The conception here advanced, of the semi-liquid nature of unconsolidated fine-grained sediments, is in accord with the results of Dr. Sorby's studies(**34**). Injection of pyroclastic material into sediments with varying degrees of consolidation down to that of a "creamy" (*op. cit.*, p.197) consistency, would naturally result in an appropriate variety of intrusion-phenomena. Ejection into the open water, and normal sedimentation would be the limiting case.

Another igneous complex of great interest occurs in Mr. MacIlveen's property (Portions 180, 175, and 162, Parish of Nemingha), about two miles south of East Gap Hill. A sketch-

* In the first part of this series of papers(14), a different explanation of the intrusive tuffs was suggested, but experience has shown it to be untenable, and it has been withdrawn(17, *loc. cit.*).

map of this is given in Text-fig.13. It recalls some of the features of the Hyde's Creek complex(17). The western side of the area sketched consists of normal, steeply dipping, banded chert,

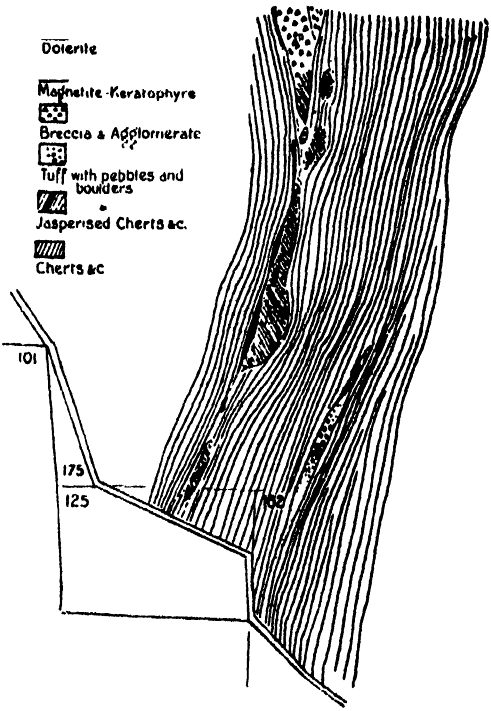



Fig. 13.—Sketch Map, MacIlveen's Igneous Complex (Nemingha Parish).

which, at its contact with the keratophyre, is impregnated with hæmatite, or is changed into red jasper. The line of contact runs in a N.N.E. direction for half a mile, and then is deflected into a direction a little west of north. The keratophyre, east of this line, varies from a rock with very little iron-ore, to one rather rich in magnetite, which has been more or less replaced by hæmatite. There are also vesicular and slaggy varieties, as at Hyde's Creek. The keratophyre includes large fragments of limestone, and an intimate, breccia-like mixture of limestone, chert, and magnetite-keratophyre; it is also traversed by small

veins of red jasper, and hæmatitic chalcedony. In microscopic structure, the rocks have many of the features of the keratophyres in the breccias of the Gap Hills. When traced northwards, the keratophyre becomes mixed with breccia, and coarse agglomerates, containing large boulders of a magnetite-keratophyre-porphyrite, while the northern extremity of the complex is a mass of coarse agglomerate, 100 yards wide, mixed with intrusions(?) of vesicular hæmatitic keratophyre, and large intrusions of massive keratophyre-dolerite, beside which is a large mass of the porphyrite. Brecciated jasperised chert occurs on either side of this. It would seem that, in this area, the intrusion of keratophyric dolerite and porphyrite was followed by a disruptive invasion of keratophyre, which broke up or brecciated the massive rocks, and emitted siliceous and ferruginous solutions, which jasperised the surrounding cherts.

Less than 200 yards south of this complex, is yet another feature of the igneous activity of no less interest, though differing greatly from the above. A band of apparently normal tuffaceous rock, at least 500 yards long, runs through Portion 162, Nemingha. It contains numerous small pebbly inclusions at the northern end, which are either angular or rounded and smooth as if waterworn. As we follow the band southwards, the pebbles increase in size until the tuff is full of large boulders, often beautifully smooth and rounded, sometimes as much as a foot in diameter. These pebbles often fall easily out of their matrix, and one would scarcely doubt, from the inspection of a pebble so isolated, that its shape was due to water erosion. South of the point where the pebbles reach their maximum size, they diminish rapidly, and in 50 yards they decrease to their original diameter of less than an inch, and the tuff-band continues thus across the road to the south without any interruption. The distance from the northern to the southern point where the pebbles are not more than half an inch in diameter, is scarcely 200 yards. On either side of this band, which reaches a thickness of 30 yards, is normal, undisturbed, fine-grained, banded chert. There is a clear affinity, in lithological character, between the tuff-matrix and the inclusions. With a few exceptions, the boulders, though

they may differ in macroscopic appearance, (they are purple, speckled grey, or green) prove to be porphyrites, composed of phenocrysts of augite and plagioclase, in a very fine-grained base. The exceptional rocks are certain rhyolitic keratophyres. The matrix is a brecciated crystal-tuff, of the same composition as the inclusions, and consists of minute fragments of these rocks, or of their phenocrysts. These are sometimes so closely and regularly packed together that it is difficult, at the first glance through the microscope, to distinguish between the matrix and the inclusion. These features must owe their origin to one or both of two causes: either the mass is a deposit of volcanic ejectamenta, which were rounded by attrition in the vent; or it is detritus from a volcanic cone, which reached above the surface of the water, and gave an opportunity for the shaping of the blocks by wave-erosion. It is difficult to decide which was the paramount factor. In either case, the rapid variation in the size of the boulders, shows that the rocks exposed were deposited near the source from which they were distributed, whether this be the centre of eruption, or the outlet of a valley which cut into the volcanic mass. The very small thickness of the mass, and the very regularly banded and minutely granular character of the sediments above and below the igneous material render the wave-erosion hypothesis difficult of application unless it be considered that this exposure is on the outer fringe of a large mass of ejectamenta, of which there is no other sign in the vicinity.

Another feature, which we may associate with the explosive action of the igneous eruptions, is to be found in the nature of the limestones. These show many features identical with those described by Messrs. Gardiner and Reynolds from the Ordovician rocks of the Tourmakeady District, County Mayo, Ireland. Besides the normal, massive, coral-bearing limestones, there are to be found, in the Parish of Nemingha, "limestones brecciated *in situ*, pink or white rocks, which, after being cracked into numberless pieces, have been recemented by the deposition of material into the cracks," and, even more frequently, "limestone-breccias, a coarse type of which contains angular blocks of lime-

stone, red, pink, or grey in colour, and horny or crystalline in texture, intermingled with angular blocks of red or green felsite," which, on microscopical examination, proves to be keratophyre or spilite, as the writer understands, is also the case with so-called felsite at Tourmakeady (see **20**). "The matrix, in which these blocks are embedded, is . . . . . . a calcareous ashy grit." The writer has "found no fossils in the matrix, although some of the included limestone blocks have yielded a rich harvest of fossils." The mass of limestone in Beedle's Freehold, Portion 163, Nemingha, is of this character. As in the case of the rocks described by Messrs. Gardiner and Reynolds, so here, "it seems impossible to avoid the conclusion that, after the deposition of the fossiliferous limestone, it was in some cases broken up by volcanic eruptions, and the fragments, accompanied by fragments of felsite, were embedded in a tuff which thus must be of later date than the limestones. It does not, however, follow that there was any very great interval of time between the deposition of the limestone, and its disruption, succeeded by the embedding of its fragments in a coarse tuff. . . . The view of the explosive origin of the limestone-breccia affords an adequate explanation of its patchy mode of occurrence." The writer cannot find words more appropriately descriptive of the brecciated limestone of the Nemingha horizon than those used by the authors cited.

One would naturally expect that brecciated cherts and claystones should occur in an analogous manner, either with or without intermingled tuff. Such rocks are well developed in the Middle Devonian Series west of the serpentines in Spring Creek, and are particularly abundant in the Eastern Series on the opposite side of the valley, which rocks are considered to be an infolded repetition of portion of the Middle Devonian Series. It is not necessary to describe these in detail; they are naturally connected by intermediate types with those described above (p.571).

There remain to be considered the more massive intrusive rocks. One of these is a porphyrite, the phenocrysts of which are greatly shattered, though the rock appears to be massive This forms a small mass in Portions 213, 214, or 216, Parish of

Nemingha. It was, unfortunately, not exactly localised, and the writer could not find it on a second visit to the place of its discovery. It is described below (see p.598).

The intrusions of dolerite at the extreme south and north of the long complex, of which East Gap Hill is the central part, are normal dolerites, the felspar of which is labradorite; but several specimens from the central portion of this mass are albitic. So far as can be seen, there is no evidence of the formation of adinole in the cherts, associated either with the albitic or the non-albitic dolerites, nor is there any difference recognisable in hand-specimen between the two types of intrusive rock. The microscope shows that the albitic rocks are thoroughly uralitised, but some of the calcic dolerites are also considerably altered. The dolerite in Portion 166, Nemingha, contains veins of epidote, with which is associated a large amount of axinite. The discovery of this is due to Mr. D. A. Porter. Axinite also occurs in the vesicles of the spilite-porphyrite on East Gap Hill. Nothing more can be said as to the source of the axinite than was said concerning that of the Nundle district, namely, that it probably is derived from the basic rocks themselves, and is not necessarily a product of the intrusion of the not very distant granite (see **17**, p.126).

There are, finally, a few small intrusions of quartz-keratophyre, of which the largest occurs on the extreme south of the area studied, Portion 171, Nemingha, while a series of smaller intrusions are to be found along the eastern side of the East Gap Hill zone of igneous rocks, and an isolated occurrence a quarter of a mile north of Housefield's Hill in the Parish of Woolomol. The characteristic feature of these rocks is the very great amount of strain-effect which they exhibit: the rock breaks with a peculiar jagged fracture, the felspars are often bent and broken, and the grains of quartz are shattered and ragged, with very undulose extinction. The reason of this great exhibition of pressure-effects is not at all clear. One may recall the fact that the keratophyres of the Nundle district showed strongly brecciated structures, and the suggestion made previously (**17**, p.164), that possibly these rocks owed their character to movements acting

on a very viscous magma, during and after its consolidation. At the same time one must note as a fact at present without explanation, the very considerable resemblance between these acid quartz-keratophyres, and the veins of quartz and albite, that occur in the serpentine in other parts of the Serpentine-Belt (see **16**, p.691).

*Barraba Series* (of Upper Devonian age).

Two divisions of the Upper Devonian Series are recognised; the lower is the Baldwin Agglomerates, and the upper the Barraba Mudstones. This is in conformity with the classification adopted in the first part of this series(**14**). However, since the lower agglomerates are frequently not developed, it seems best to extend the term Barraba Series to comprise the whole of the Upper Devonian formation, and to recognise the Baldwin Agglomerates merely as a basal zone, which may or may not be present. Both divisions occur in the Tamworth District. We commence with the discussion of the agglomerates.

It was stated in a previous paper(**14**, pp.500-1) that the coarse agglomerates did not, as was previously supposed, rest unconformably on the banded claystones of what is now termed the Upper Middle Devonian Series, where they are exposed on the hills about Cleary's Selection, to the north-east of the Tamworth Common. The inference was drawn chiefly from a consideration of the lithological similarity between the matrix of the agglomerates, and the tuffs and breccias in the underlying Middle Devonian, as well as the overlying Upper Devonian rocks, and the criteria for the lithological proof of a conformity through continuous oscillatory change of condition, were discussed from a hypothetical point of view. This conclusion can now be thoroughly substantiated on stratigraphical grounds. The coarse agglomerates may be traced round the face of the hills from the Two-Mile Bridge, on the Peel River, south-east of Tamworth, until they meet the fault in Spring Creek, on the northern boundary of the Common. The boundary of the agglomerates is at every point, in complete conformity with the strike of the Middle Devonian rocks, on which they rest. Particularly clear proof of this, is afforded by the sections exposed

in Long Gully, Cleary's Gully, the small gorge in portion 246, and again in Spring Creek in portions 148 and 237, and is sufficiently indicated in the map herewith (Plate l.). The agglomerates are interstratified with mudstones, and these also show dips conformable with those of the underlying rocks. The small gorge cited above shows a very instructive exposure of these rocks. Again, as mentioned by the previous authors, there are frequently short irregular beds of pebbles in the agglomerates (9, p. 23), and if these represent the bedding-plane of the agglomerates, as observations at Borah Creek Gap, in the Baldwin Mountains, near Manilla, convinced the present writer that they do, there is additional proof of the conformity here claimed.

The mode of origin of the agglomerates is not directly obvious. They consist of fragments of chert, andesite, porphyrite, keratophyre, and rhyolite, with some limestone, set in a matrix exactly similar to that of the normal pyroclastic rocks, which is made up of close packed fragments of crystals and rocks, evidently derived from rocks of the same nature as those which occur as included pebbles. These pebbles are frequently very smooth and rounded, particularly in the lower portion of the series, though some angular blocks occur. Professor David was of the opinion that they were waterworn in many cases, but was doubtful whether magmatic corrosion had not played some part in the rounding of some of the larger blocks (9). The boulders and fragments reach a diameter of nearly a foot in the neighbourhood of Cleary's Hill, but diminish in size as they are traced to the north-west or south-east, and are rarely more than half-an-inch in diameter, where the rock appears on the railway-cutting by the Two-Mile Bridge, or in the valley of Spring Creek. The source of these boulders was, therefore, in the neighbourhood of Cleary's Hill.

In many features these agglomerates are analogous to those previously described (p. 574), but differ from them in their immense thickness, which reaches a maximum in the Tamworth Common of nearly 2000 feet, but dies out by interdigitation with Barraba mudstones. These interstratified mudstones are richer in *Lepidodendron* than any other rocks in the district, and casts of this plant

sometimes occur in the igneous materail itself. There is thus less reason in this case to doubt the possibility of a volcanic cone rising above the surface of the sea. It must be noted, however, that there is not any great thickness of agglomerate, uninterrupted by intercalations of radiolarian mudstone, so that the sea-floor must have been sinking rapidly, and the islands, if formed, would not be of long duration. The largest rounded boulders are in the base of the series, lying on undisturbed claystones. The intercalated mudstones were not deposited on steep slopes, but are quite conformable with the claystones below the agglomerates, so far as can be determined; and the upper members of the agglomerate series show little or no sign of water-erosion.

The mudstones, and pyroclastic rocks have a varying degree of resistance to erosion. Strongly resistant bands, forming well marked outcrops, may often be traced for some distance, others die out rather irregularly. The map, in this region, does not pretend to have more than a general accuracy.

The mass on Cleary's Hill, which is taken to represent the base of the series, owes its great width of outcrop, not to its thickness, but to the fact that it slopes down the face of the hill. A certain amount of faulting occurs where Cleary's Gully debouches on to the Common, which makes estimates of thickness in this region very unreliable.

A second occurrence of the Baldwin Agglomerates is indicated by the rocks west of the limestones in Spring Creek, forming the ridge between the Manilla and Moore Creek roads. Here the coarse conglomeratic character has quite disappeared; the rock is merely a breccia, of medium grain-size, and the interbedded mudstones greatly predominate over the pyroclastic rock. The several bands of the agglomerate occupy the whole of the western part of the Tamworth Common, and, on the extreme west, are bent into an anticline. This anticline may be traced northwards to Moore Creek, but becomes rather flattened out. While much of the material in the agglomerate in this region, may have been derived from the centre of eruption near Cleary's Hill, there was evidently another point of eruption towards which these rocks may be traced,

which is indicated by the prominent hill in Housefield's Selection, Portion 120, Parish of Woolomol. This consists of coarse bouldery agglomerate, the inclusions of which are similar to those on Cleary's Hill, and are so rounded as to resemble even more closely, normally waterworn pebbles, and these are abundant in the upper portion of the mass which is at least 200 feet thick, and is free from interstratified mudstones. North of the hill is a small dyke of keratophyric quartz-felpar-porphyry, fragments of which also occur in the agglomerate.

The horizon of the Baldwin Agglomerates seems to be represented south of the Peel River by the mass of agglomerate, that runs through the eastern corner of the town of West Tamworth, and through portion 27, Parish of Calala, as well as by a band of tuff in the valley of Goonoo Goonoo Creek, portions 15 and xx. Evidently the agglomerate has greatly thinned out in this direction. No continuation of the great mass of agglomerate that comes down to the north side of the river, at the Two-Mile Bridge, can be traced on the southern side; which is a further piece of evidence in favour of the view, that the Peel River alluvium conceals an important fault.

The line of junction between the Middle and Upper Devonian claystones and mudstones is quite an indefinite one, when there is no intervening development of agglomerate, as is the case with the majority of the boundary line drawn through the Parish of Woolomol. This line is, therefore, almost entirely arbitrary, and was drawn merely by reference to the occurrence of the limestone on the east and agglomerate on the west. The claystones of the Middle Devonian Series, when they have not been silicified into cherts, can rarely be distinguished from those of the Upper Devonian Series. There is probably a fault between the limestones and agglomerates in sections 41 and 44 respectively of the Parish of Woolomol, as they are much closer to one another than would be otherwise possible.

Above the agglomerates, extend the monotonous series of thick claystones, and mudstones, occasionally radiolarian, interstratified with some tuffs, just as has been described for the Barraba Series

in previous papers. These occur typically in the south-western corner of the area shown in the map herewith. The fossils of this zone, apart from the radiolaria, which may occur in the tuffs as well as the claystones (see 10) are confined to *Lepidodendron australe,* and fluted stems like Calamites, just as occur in the rocks of the Upper Middle Devonian Series.*

These fossils are particularly abundant in the gully traversing portion 59, Tamworth, "Porter's Gully" of the previous authors, where they occur in the mudstones that are interbedded with the Baldwin Agglomerates. They are fairly common elsewhere in this association. It remains to add that intrusions of felspathic tuff into the Upper Devonian mudstones, show just the same features as are exhibited in Figs. 9-12. Not infrequently the material of the tuff has been more or less impregnated with prehnite.

*Tectonics of the Devonian Series.*

It is now possible to summarise the main tectonic features, discovered by tracing such stratigraphical horizons as the district affords. For the central feature, there is the well-marked elongated pericline, the axis of which runs in a north-westerly direction up the valley of Seven-Mile Creek. Northwards, this is followed by close-packed anticlines, and "schuppen"-strips, extending to Moore Creek. Southwards, there is an interruption in the strike marked by the Cockburn River syncline, which has a north-easterly strike; and a parallel anticline to the west of it, the axis of which crosses the railway-line near the Nemingha platform. The Seven-Mile Creek pericline is thus the result of intersecting folds. South and east of this are the close-packed folds and "schuppen" fault-strips, that form the greater part of the Parish of Nemingha, and occur with even greater intensity of disturbance east of the serpentine.

* With regard to the remarks of the previous authors(9), concerning the downward range of *Lepidodendron*, nothing has yet been found to invalidate their conclusions. No *Lepidodendron* has been found at a horizon that can be proved to be lower than that of the Tamworth-Moore Creek Limestones, but some Lepidodendra, that occur in Loder's Gully, and in the railway-cuttings east of the Nemingha Siding, must be very close to the horizon on which the Moore Creek limestone would occur, if it were developed in this region.

Westwards from the pericline, the series continues with a south-westerly dip and decreasing inclination. There are probably one or more faults running to the west of the Igneous Zone, causing repetition of it. Again, there are the faults in the Tamworth Common, at Cleary's Hill, and at Spring Gully, which seem to extend to Moore Creek. These have a roughly meridional direction. The strata, however, do not follow this direction, but swing round to the north of the Tamworth Common, till they are dipping due south. This bend possibly represents the edge of another syncline with a N.E.-S.W. axis, of which the south-western limb has been cut off by the fault in Spring Creek valley. The strata to the west of this fault are flattened out, and are bent into a syncline, which can be traced northwards to Moore Creek, and southwards across the Peel River. Its axis runs in a direction trending N.N.W. to S.S.E.

Recognisable zones, wherever they have been found, are seen to have been repeated by faulting, and it is safe to assume that more strike-faulting must be present undiscovered in the monotonous series of mudstones and tuffs in the Upper Middle Devonian, and the Upper Devonian Series. The rarity of faults in the sections exposed in the railway-cuttings should, however, warn one against over-estimating this feature.

In addition to these roughly meridional faults, there are others which are more nearly parallel to the axis of the Cockburn River (and Tamworth Common ?) syncline. Thus there are two directions of folding and faulting in the district, with some lines following an intermediate direction. The question as to the relative age of the two at once arises. There is not yet, however, sufficient evidence to show the nature of the thrusts and movements that have brought about this reticulation of tectonic lines. In adjacent districts now under investigation, a different intersection of tectonic lines is observable, and, until more is known of these areas, a discussion of the tectonics of the region would be premature.

*Thickness of the Devonian Series.*

The facts recorded in the foregoing paragraphs show that the attempt to find definite continuous horizons, from which the tec-

tonic structures and the thickness of the formations involved might be exactly determined, has been in a large degree unsuccessful. It has, however, been proved that some faulting is present, producing a greater degree of repetition of strata than was assumed in the previous estimate of the total thickness of the series, though the thickness of the individual beds of limestone, claystone, and tuff, and the total apparent thickness, were measured with great care. As yet, however, it is quite impossible to determine the exact amount which must be deducted from that total (9,260 feet). Plotting the old line of section on the new map, we find that the lower portion of the Baldwin Agglomerates on Spring Creek was included in the earlier total. The agglomerates here are as finely granular as much of the pyroclastic matter in the Middle Devonian Series, and they would naturally be classed with the latter, before detailed mapping had shown their connection with the deposit of large boulders on Cleary's Hill. To obtain the total apparent thickness of the Devonian rocks in this district, we must, therefore, add the remainder of the Baldwin Agglomerates, about 1000 feet and the thickness of the Barraba mudstone, *apparently* about 2400 feet. The columnar section given in Fig. 1 shows the relative thickness of the various subdivisions of the Devonian Series as far as can be ascertained at present.

*Conditions attending the formation of the Radiolarian Rocks.*

As this district is frequently cited as a classical example of the development of a series of radiolarian rocks in comparatively shallow water, the subject should not be passed over in the present communication; but, as further studies are in progress in adjacent areas, where similar rocks are developed, and much remains to be investigated, we will merely note the bearing of the new observations on the views of the authors who studied the question here previously. According to them, the radiolarian rocks "were deposited in clear seawater, which, though sufficiently far from land to be beyond the reach of any but the finest sediment, was, nevertheless, probably, not of very considerable depth"(9). This conclusion was based on the following considerations:—(1) The presence of ripple-marking, (2) the abundance of plant-remains indicating the

proximity of land, (3) the absence of any coarse terriginous sediment, and (4) the intercalation of coral-limestones. The present writer concurs entirely with these conclusions. The only consideration which gave rise to some doubt was the possibility that the Baldwin Agglomerates, now proved to be interstratified in the radiolarian series, might owe the rounded character of their inclusions to water-erosion. The present study, however, tends to the conclusion, that, even if this were so, as seems possible in some cases, this would not indicate the presence of a persistent coastline, but only the development and rapid destruction of islands, which were the summits of masses of agglomerate erupted from vents in the flat floor of the sea. The development of the Baldwin Agglomerates marks an epoch when such great eruptions were in progress. It is not yet clear that the building of volcanic islands characterised the eruptions, that produced the Igneous Zone in the Middle Devonian Series. The eruptions may have occurred at a considerable distance from a persistent coastline. Except for the products of these great eruptions and the many minor convulsions, the sediments are of the finest grainsize, and largely composed of the remains of radiolaria. The depth of the sea in which they were laid down, must have been sufficiently great to give the overburden requisite for the production of intrusive tuffs, and sufficiently shallow to permit of the formation of ripple-markings, and coral-reefs. The exact depth at which this balance was obtained cannot be estimated with any precision. Doubtless it varied somewhat, as the presence of definite zones of limestone would lead one to infer; but as the radiolarian rocks, with interbedded and intrusive tuffs, adjacent to the limestones, are quite similar to those elsewhere in the series, there is no reason to assume that these variations were large. We may, perhaps, conclude that there is no evidence that the radiolarian rocks were formed at a depth less than the maximum at which it was possible for the limestone to have been formed. The work of Darwin, Dana and many others has shown that the reef-building corals in the modern seas, do not live at greater depths than about fifteen or twenty fathoms, though certain isolated forms extend much further down. The corals of the past seem to have

had the same general range. [The evidence for this statement has been recently summarised by Grabau(21)].

*Serpentines*, etc.

As in the areas described in former papers, the serpentine follows the line of fault, which separates the highly disturbed rocks of the Eastern Series, from the less crumpled rocks, which lie to the west. The band of serpentine varies greatly in width. At the southern end of the map, on Nemingha Creek, it is not more than 50 yards across, and is even narrower a short distance to the north. It is much broader at the head of Spring Creek, being nearly 300 yards wide there, and then tapers gradually northwards, dying out completely in Portion 144 of Nemingha Parish. The fault-line may, however, be traced into Portion 169, where there is a small lenticular area, about ten yards long, composed of ferruginous carbonate rock, such as represents the serpentine in other portions of the Serpentine Belt, as in the Nundle and Crow Mountain districts.

The serpentine is mostly of the sheared, chrysotilic variety; some massive bastite-serpentine is present, and a little antigoritic rock. Other alteration-products are rare. A chalcedonic replacement of bastite-serpentine occurs in Portion 176, and opal, with dendritic markings, in Portion 129. Near this was found a small patch of olivine-gabbro, only a few yards in extent. The felspar of this rock was converted partly to saussurite, and partly to clinozoisite. Small segregations of chromite occur in the serpentine. With this, hyalite has been found by Mr. D. A. Porter(4).

In several places there are abundant intrusions of a porphyritic or massive dolerite in the serpentine. This rock has exactly the same characters as that occurring in a similar situation in the neighbourhood of Bowling Alley Point(17, p. 156). The individual masses are quite small, ten or twenty yards long, and about half as wide. Some are rather sheared. None appear to cut the serpentine transversely, but the individual masses may be fragments of larger instrusions torn apart by movements in the body of the serpentine. No dolerites of this character have been found outside of the serpentine.

The tectonic features of the serpentine-intrusion differ from those normal elsewhere in the Serpentine Belt, in the sudden bending of the serpentine into a north-north-easterly direction, where it approaches the granite. That this is not due to the wedging outwards of the strata by the invasion of the granite, is shown by the fact that the strike of the Devonian rocks continues almost unchanged, and is cut obliquely by the serpentine. We may, perhaps, see in this some evidence that the stresses, which determined the Cockburn River axis of folding, had begun to make their influence felt when the intrusion of the ultrabasic rock occurred.

*Moonbi Granite.*

About fourteen square miles of the area covered by the present map are occupied by granite. This is the southern extremity of a batholith which extends from Bendemeer to the north, in the direction of Attunga, to the north-west. According to Mr. E. C. Andrews(12), it is invaded by the more acid granite of Bendemeer, which forms resistant masses that stand out in relief above the more basic Moonbi granite. On the east, the granite is bounded by the jasperoid rocks of the Eastern Series, which, also have a high relief, and form the prominent peak of Bullimballa (Black Jack), about six miles to the N.N.E. of Moonbi. Both these prominences are, however, outside the limits of the area under discussion.

The granite is of coarse or medium grainsize, even-grained, or slightly porphyritic. It is fairly potassic, containing a considerable amount of orthoclase and biotite. Hornblende is the dominant coloured constituent, and sphene is generally present in notable amount. Mr. Andrews has compared this granite with the sphene-granite-porphyries of northern New England, to which he attributes an early Mesozoic age(12).

The granite is invaded by a variety of vein-rocks; aplites, with druses containing crystals of quartz with a mica like zinnwaldite, occur associated with veins of quartz bearing small amounts of molybdenite, in the high ridge between the Cockburn River and Moore Creek. Various types of pegmatite, either graphic quartzose pegmatite, or more richly felspathic rocks, often containing a little

tourmaline, are to be found near the Kootingal railway-station, and a beautiful garnetiferous, and graphic tourmaline-aplite, is developed on the travelling stock-route, in the north-eastern corner of the Parish of Tamworth. Dykes of finely granular rocks of intermediate composition are found, and are best described as microdiorite and micromonzonites, or diorite and monzonite aplites; and a peculiar lamprophyre, which has the mineralogical composition of an augite-minette, and contains spherulites of quartz and felspar. A few dykes of pegmatite and quartz-porphry extend from the granite into the surrounding Devonian rocks, but only for a short distance. This absence of an extensive series of dyke-rocks is a characteristic feature of the Moonbi granite.

The metamorphosing effect produced by the granite on the surrounding rocks has been considerable, and is especially noteworthy in the limestones, and the pyroclastic rocks. In the latter, it generally has the effect of causing the augite to change into the stable actinolite, rather than into chlorite, the ilmenite is replaced by sphene, and the felspar is recrystallised, sometimes as a mosaic of minute, indeterminable, untwinned grains, and sometimes in clear crystals of andesine. In the more altered types, abundant tiny plates of biotite are formed, the calcite in the vesicles, or irregularly distributed throughout the rock, passes into garnet, and, still more rarely, some secondary pyroxene is developed at the expense of the amphibole. These rocks are best developed in a railway cutting east of Tintinhull, while the most altered garnetiferous types occur in Portions 113, 123, and 169, Parish of Nemingha. Rocks with secondary pyroxene also occur in the north-eastern corner of the Parish of Tamworth. Associated with the garnetiferous rocks in Nemingha, are massive hornblende-schists, representing former dolerites, and garnetiferous hornblende-schists, that were, in all probability, amygdaloidal spilites. The hornblende-schists, which extend southwards from Portion 157, and those occurring in Portions 42, 63, and 64, Nemingha, are probably also altered spilites. The zone of alteration of the igneous rocks varies somewhat in width; generally, it is about a quarter of a mile across.

The zone in which alterations of the limestone are recognisable is less extensive. The limestone in Seven-Mile Creek is greatly altered within a furlong of the granite, but, beyond that, it is unchanged or merely recrystallised, with the partial obliteration of the fossils. In the more altered parts, the limestone is changed to silicates such as garnet, wollastonite, diopside, and vesuvianite; but sometimes traces of the fossils are preserved among them, as noted by previous authors.

In the Parish of Nemingha, the limestones are much less altered. All the fossils have been obliterated near the granite, but comparatively little silicate-mineral has been formed. Where, however, the limestone was originally mixed with tuffaceous material, there are druses filled with calcite, epidote, and vesuvianite; and in the adjacent, often quartzose, tuffs there are regenerated felspars, with diopside and garnet. These druses, doubtless, represent original inclusions of limestone in pyroclastic rock.

The clayslates and cherts show least sign of alteration. The metamorphic zone extends barely 100 yards from the boundary of the intrusion. The most altered rocks are those which form the small patch of sedimentary rock that is completely surrounded by granite; this occurs in Portion 76, Tamworth. These consist of a highly crystalline, biotite-schist, containing veins and knots of granite and pegmatite. Less altered schists occur at the foot of the hill in Portions 42 and 64, Nemingha, and in Portions 178 and 183, Tamworth. Generally, however, the contact of the sedimentary rock and the granite is hidden by drift. The greater part of the boundary, as plotted on the map, was obtained by linking up isolated exposures of the contact-line, seen here and there in creek-beds.

The form of the granite-mass calls for comment. The previous authors showed that the margin of the granite in Seven-Mile Creek is concordant with the strike of the sedimentary rocks, and stated that the latter dip *beneath* the granite, which, they accordingly suggest, is of the nature of a laccolite(9). While unable to confirm this observation, the writer finds that the constant dip of the sediments *towards* the granite is a marked feature of its western mar-

gin, and certainly suggests that the limits of the granite-intrusion may have been determined by the tectonic structure of the invaded rocks. It seems quite clear, however, that the granite, if laccolitic, did not extend far over the Seven-Mile Creek anticline. The rocks that form this structure are very little altered, while the rocks, which, in Erdmannsdörfer's view(24), are to be regarded as the Devonian and Carboniferous rocks altered by the overlying laccolite of the Brocken granite, are the highly altered series, that form the Eckergneiss.*

The southern margin of the granite is quite transgressive. It seems to be no more than a coincidence that part of it is approximately parallel to the axis of the Cockburn River syncline, for elsewhere it cuts right across the axis, and also across the several repetitions of the Lower Middle Devonian Series, the Serpentine Belt, and invades the Eastern Series. Hence we may conclude that the folding of the Devonian rocks, both along the main structural N.N.W.-S.S.E. axis, and the subsidiary N.E.-S.W. axis was accomplished before the intrusion of the granite occurred. The absence of any noteworthy gneissic structure along the margin of the granite is also evidence towards the same conclusion.

### *Tertiary Basalt.*

A small plug of basalt occurs on the western edge of Portion 83, Parish of Woolomol. It is roughly oval in shape, and about sixty yards long. It does not give any noticeable relief. The rock is granular or aphanitic, with small crystals of olivine, and is massive or slightly vesicular. The microscope reveals the presence of cognate xenoliths of olivine, pyroxene, and picotite, and very interesting vesicles filled with natrolite and opal, which seem to be of primary origin. In general character, the rock is quite analogous to the majority of the Tertiary basalts in other parts of the State.

### *Terrace-Gravels.*

On either side of the Cockburn and Peel Rivers, may be seen terraces of gravels lying thirty or forty feet above the present

* Goldschmidt, however, doubts the possibility of such gneisses being produced under so small a pressure as Erdmannsdörfer assumes (26).

flood-plain. The best examples of these are the gravels south of the Cockburn River, near Kootingal railway-station, which are exposed in the road-cutting by the Public School. A large terrace covered by gravel, also occurs on the point between the Peel River and Goonoo Goonoo Creek, in Portions 15 and 21 of Calala Parish, and smaller masses at other points, *e.g.*, by the railway-viaduct at West Tamworth, in Portions 1 and 30 of Calala Parish, and north of the Peel River by Nemingha railway-platform. These consist, for the most part, of pebbles of jasper and quartz, with a binding of clay and red loam. Scattered pebbles of rocks of the Eastern Series can be found in several other spots, and doubtless represent other terraces, now more or less destroyed. Practically all the pebbles in the terrace-gravels have been derived from the Eastern Series.

*Drift.*

The masses of drift have not been separated from the terrace-gravels in the map, though they are a noteworthy feature in the agricultural geology of the district. We may distinguish stream-drift, the material brought down and deposited in an irregular manner, by the tributaries of the main rivers, and superficial drift, flanking the bases of the hills and accumulating through general soil-creep, etc., and, generally, any widespread deposit not flood-plain alluvium, which completely hides the underlying rocks.

The stream-drift deposits are well seen in the valleys of Nemingha and Gap Creeks, in the south of the Nemingha Parish. The latter has entirely filled its valley, and does not debouch as a single stream; the former had also a wide distributary area, but has recently been confined to a single channel. Spring Creek, by the serpentine, has also a great accumulation of detritus; and isolated patches of gravel, high above the present creek, as on Portions 70 and 85, indicate where the older stream-drifts of this creek joined with the terrace-gravels. These drifts cover the western margin of the serpentine to a great extent. To a combination of stream-drift and soil-creep is due the great thickness of gravel and soil along the foothills of the range behind Tamworth, and, in particular, that between Long Gully and Cleary's

Gully. Again, the drifts covering the margin of the granite in the Parish of Woolomol have this conjoint origin. The very large amount of drift at the present head of Seven-Mile Creek has been preserved in its present position by the capture of the headwaters of this stream, which now flows northward as Daruka Creek, to join Moore Creek. It is probable that the broad areas of drift that form the central part of the Parish of Woolomol similarly owe their preservation to the capture of their parent stream, of which the headwaters are known as Levy's Springs, by Spring Creek, which runs through the Tamworth Common.

Where the drift is entirely derived from mudstones, it decomposes into a clay suitable for the manufacture of bricks. The clay-deposits of this character at West Tamworth are more than twelve feet thick.

A considerable thickness of stream-drift lies below the alluvium of the flood-plain of the Peel River. From records in the Department of Public Works, kindly placed at the writer's disposal by the Chief Engineer for Railway Construction, it is to be seen that the bed-rock of the Peel River valley at the railway-viaduct lies at a depth of forty to fifty feet below the present land-surface. The basal portion of the drift consists of from two to four feet thick of clay, which is covered by clay, gravels, and drift up to a thickness of twenty-four

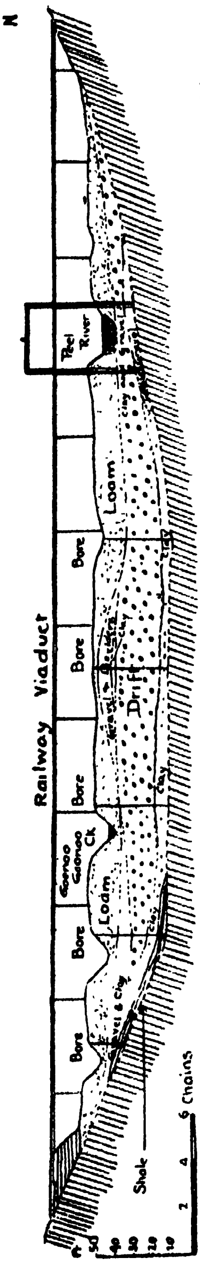



Fig. 14.—Section showing the alluvial deposits in the valley of the Peel River at Tamworth, from data supplied by the State Department of Public Works.

feet, with a bank of gravel and boulders in the centre of the valley ten feet high above this. (See Text-fig.14).

### *Alluvium of the Flood-plain.*

The broad flood-plain of the two rivers is covered with a soft, black loam, of great agricultural value. In places, it is more than a mile wide, and is of varying depth, generally ten to fifteen feet. This is the depth of the soil by the railway-viaduct.

## PETROLOGY.

The following notes are based upon a study of about two hundred thin slices of rocks from the Tamworth district, of which seventy came from the collections of the New South Wales Geological Survey, and of the University, and were those used by Messrs. David, Pittman, and Card, in the preparation of the previous paper on this area. Attention has been devoted chiefly to the igneous rocks; the sedimentary and metamorphic rocks show a much smaller range of interesting features. The chronological order has been followed as far as possible in the sequel.

### *Eastern Series.*

The basic rocks of the Eastern Series are spilites, vitrophyres, and hornblende-schists, the product of the contact-metamorphism of the spilites. The spilite, which crosses the head of Spring Gully, south of Portion 189, Nemingha, has a poorly developed ellipsoidal habit, is massive or slightly sheared, and of fine grain-size. It has a well marked subvariolitic structure (1354). The felspar has been largely changed to epidote, the remainder is glassy, and frequently untwinned; it is probably albite. The pyroxene is changed to chlorite, or remains quite fresh. It is a colourless diopside. Magnetite-crystals occur in abundance. There are small veins of epidote, quartz and chlorite. A completely epidotised rock was found by Mr. Aurousseau, as a pebble in Spring Creek, doubtless derived from the Eastern Series. It is very like the Pre-Cambrian spilitic dolerite, from Tayvallich,

in Argyllshire, which was described by Dr. Flett(41), a specimen of which was kindly given to the writer by Dr. H. H. Thomas (a slice from specimen 13218 of the collection of the Geological Survey of Great Britain.) The preservation of the subvariolitic structure in the epidote is very distinct.

The amphibole-schist, derived from the metamorphism of the spilite, which occurs in Portion 155, Nemingha, is considerably decomposed (1338). The original structure has been entirely lost, and the large grains of plagioclase have been replaced by finely granulated albite, while the remainder of the rock consists of matted chlorite and actinolite, dotted with minute grains of titanomorphite. Another form of altered spilite occurs in the north-eastern corner of the area mapped in Portion 64, Nemingha (1323). It has completely lost its original texture, and has now the habit of a fine-grained amphibolite. It consists of a mosaic of interlocking grains of untwinned albite, actinolite scattered irregularly in isolated prisms or sheaf-like aggregates, and a little irregularly granular sphene, sometimes in small clusters. A few prisms of apatite are also present. Slide 1305, from the same locality, is probably an altered vesicular magnetite-quartz-keratophyre-tuff. It is a strongly schistose rock (see Plate lii., fig. 1). The grey, dusty, felspathic groundmass is too minutely granular for determination. It is sprinkled with small isolated prisms of hornblende, and well formed crystals of magnetite, evenly though not densely distributed throughout the rock. Interlaminated with the grey felspathic portions, or forming fragments in it, or apparently filling vesicles, is a mosaic of quartz-grains, with abundant prisms of actinolite. The rock has been so cut by "schuppen" shearing, that the form of these has been largely lost. They perhaps result from the recrystallisation of interlaminated and fragmentally included sedimentary material, and the infiltered infilling of vesicles.

The vitreous rock from Pine Hill (1119) has been described above (p. 547). It is more acid than most of the other rocks of spilitic suite in the Eastern Series.

*Igneous Rocks in the Middle Devonian Series.*

These rocks include many types of dolerite, spilite, and keratophyre, and the pyroclastic rocks, as well as the metamorphosed equivalents of these.

The dolerites differ from one another in texture, the composition of the felspar, and the nature of the pyroxene. The quartz-dolerite, which forms a very small mass in Portion 110, Nemingha (1132), is characterised by the presence of basic andesine or labradorite as the dominant mineral, as is also that which occurs near the magnetite-keratophyre in Portion 175,(1107, 1128), and that which invades the porphyritic spilite on the northern end of East Gap Hill (see Text-fig. 4). These rocks have a granitoid texture, the felspar-prismoids, being approximately idiomorphic, and often strongly zoned. The augite is of the normal character, slightly decomposed, and possessing a large optic axial angle. Quartz occurs in large grains, or in granophyric intergrowth with felspar. Ilmenite is abundant, and apatite rare, though some large prisms occur. The chemical composition of 1132 is given on page 74a; the composition of the felspar calculated from this would be $Or_7Ab_{47}An_{49}$, or, reckoning orthoclase as albite,$Ab_{52}An_{48}$, which corresponds with the result of the optical determination. The dolerite on the north of East Gap Hill contains some highly granophyric masses, while there is also some uralitised albitic dolerite, from Portion 204, Nemingha, which cannot be distinguished macroscopically from the adjacent calcic variety.

The porphyrite, which occurs in Portion 158, Woolomol(1162), is rather different from these. This is so free from any sign of contact-metamorphism, though within the zone of altered rocks, that some doubt must remain, as to whether it is really coeval with the Devonian doleritic series. It is, however, quite unlike any Tertiary basic rock known to the writer. It has a fine-grained base, consisting of prismoids of andesine, with chlorite replacing augite, titanomagnetite, a very little quartz and apatite. The phenocrysts are sometimes as much as 3 mm. in diameter. They consist of plagioclase, with zones of liquid inclusions, and have commenced

to decompose. Its composition, determined from the Carlsbad-albite twin by means of Professor Becke's diagram,* is $Ab_{60}An_{40}$. The phenocrysts of augite are generally rather smaller, have a large optic axial angle, and are decomposed on the periphery.

Dolerites also occur with albite as their felspar, and of these there are two main groups, the granitoid and the poryphyritic. Rock 1120, which occurred adjacent to the rocks with basic felspars in Portion 175, Nemingha, is like them in texture and grain-size. The felspars are fresh and dusty, are slightly zoned, and have the composition of albite-oligoclase. They are almost idiomorphic, and are surrounded by a micrographic intergrowth. The pyroxenes are almost completely changed to chlorite, ilmenite is abundant, and quartz appears in a few separate grains, as well as in the intergrowths. A few large grains of apatite occur, but these are not present in the intergrowth. From its textural identity with the calcic rocks of the district, it seems possible that this may have been derived from such rocks by albitisation. Other albitic rocks are represented by slides 1024, 1030, 1039, 1048, 117 occurring respectively with porphyritic spilites at Tintinhull (Portion 123, Tamworth), in Portion 202, Nemingha, with spilites at Pullman's Hill, Portions 205, 48, Nemingha, in Portion 204 (the northward continuation of the belt of calcic dolerite which invades the porphyritic spilite of East Gap Hill), and in Portion 181, at the southern end of West Gap Hill, associated with pyroclastic rocks. The first four of these occur about half a mile from the nearest outcrop of the granite, and there is no definite evidence of contact-metamorphism. The plagioclase is clear, and very little, if at all, spongy. Quartz-grains occur in small amount, but there is no granophyric intergrowth. The ilmenite has been more or less converted into titanomorphite.

The porphyritic dolerites of Tintinhull have already been briefly described. They are sometimes aphanitic, with small often reddish phenocrysts of felspar (1138, 1160). This is a water-clear albite,

* As yet unpublished, but in use in the laboratory at Vienna, during the writer's visit in 1914.

quite idiomorphic, and either isolated, or associated in glomero-porphyritic aggregates, which are sometimes in ophitic relation to pseudomorphs after pyroxene. The original pryoxene phenocrysts were small and not abundant, and are now completely uralitised. The groundmass is very fine-grained, sometimes massive, sometimes with a strongly marked flow-structure, in which there are small string-like accumulations of magnetite. The constituent minerals of the groundmass are minute laths of clear felspar, amphibolitised and chloritised granular pyroxene, and magnetite. Epidote occurs with quartz in the vesicles, which are often abundant. Secondary silicification sometimes has replaced more or less of the felspar-phenocrysts (as in 1138), and veins of quartz may traverse the rock. Small accumulations of dusty hæmatite are not uncommon. The rock of Pullman's Hill, 48 Nemingha, is quite similar to the above, showing a good flow-structure (1130). Its chemical composition is given on p.602; the composition of the felspar calculated from this analysis is $Or_4Ab_{56}An_{40}$, or $Ab_{64}An_{36}$, which is rather more basic than the composition determined by optical measurements. This discrepancy, no doubt, arises from the presence of chlorite and epidote in the base. The spilite in the eastern side of Portion 65, Nemingha, is similar to the above (1150), so much so that there can be no doubt that it is really a portion of the same rock-mass separated from the Tintinhull and Pullman's Hill spilites by folding and faulting. As remarked, the structure of these rocks is very similar to that shown by the porphyritic spilites in the Eastern Series in the Nundle District, and is sufficiently illustrated by the photomicrograph already given of that rock. (See (17), Plate xxv., fig.3).

Associated with these rocks, and apparently passing into them, is a less finely granular albitic rock, which shows the typical sub-variolitic spilite-texture, and has finely crystalline margins about quartz-filled vesicles. Its pyroxene has now been completely uralitised(1166). The albite-dolerite already described (1024) is in similar association with the spilites at Tintinhull.

The porphyritic spilites of East Gap Hill have the same mineralogical features as those of Tintinhull, but differ in grain

size. If they be a portion of the same rock-mass as the Tintinhull rocks, as seems very probable, the conditions of consolidation must have been different. The porphyritic spilites on East Gap Hill are very coarsely granular, where they are invaded by the dolerite near the summit of the hill, and diminish in grainsize, and increase in vesicularity as they are traced to the south. The more coarsely granular types contain large phenocrysts in a subvariolitic groundmass (1032, 1033, 1168). The phenocrysts are idiomorphic plagioclases, but are moulded on augite, when the two minerals come into contact. They may be as much as 8 mm. in length. It is difficult to determine their composition, as the crystals are rather dusty, and full of partially chloritised zonary inclusions of the groundmass, and of epidote. They seem to be albite, however. They are not zoned, and have been more or less replaced by a mosaic of minutely granular quartz, which may, in some cases, leave only the outer rim of the felspar intact. Phenocrysts of augite also occur, either singly or in aggregates. They are rather decomposed, and may include large grains of magnetite. Some octahedra of magnetite also form phenocrysts. The groundmass consists of lathy oligoclase with forked microlitic extensions, skeletal forms of ilmenite, as well as definite grains, and small grains of titanomorphite. The pyroxene, which was originally in the form of small prisms, is now completely changed to chlorite and epidote. Irregular patches of secondary quartz-mosaic also occur in the base. The vesicles are numerous, and differ in their content of minerals. The following types have been noted:—

(*a*) Outer margin, epidote; central portion, orthoclase.

(*b*) Outer margin, epidote and chlorite; inner portion, quartz.

(*c*) Outer margin, epidote and chlorite; inner portion, quartz-mosaic.

(*d*) Outer margin, epidote; central portion, chlorite.

(*e*) Outer margin, epidote; inner portion, chlorite; centre, epidote.

(*f*) Epidote, chlorite and axinite, irregularly arranged.

(*g*) Epidote, chlorite, felspar and axinite.

The southern end of this mass is very fine-grained, and exceedingly vesicular, and passes without any definite break into the mass of pyroclastic rocks that are described below.

A single sill of spilitic dolerite invades the clayslates, at the Municipal Quarry in the Tamworth Common. It is a rock of medium to fine grainsize, with a subvariolitic texture (1018). The felspar is clear albite, with a few inclusions of chlorite. It forms long plates with occasional skeletal extensions. Intersertally are minute laths of felspar, and a small amount of granular quartz, mixed with a considerable amount of chlorite. Many small, brown grains of augite occur, together with a few larger ones, which are fairly fresh. There is also a little magnetite. Some secondary carbonates are present.

Specimen 1303, which represents what is probably a small intrusion in Portions 213 and 216, Nemingha, is a most interesting rock. In hand-specimen, it seems to be a normal but rather decomposed dolerite, with large augite-phenocrysts. The microscope shows that its constituent grains are mostly shattered. The phenocrysts are large, zoned augites, similar to those occuring in certain andesites and porphyrites. The edges of the broken fragments of them are quite sharp, and show no sign of resorption. Generally they are yellow-brown or green, and are markedly pleochroic. Frequently adhering to these crystals are fragments of green partially chloritised glass, containing laths of acid plagioclase and spherulites of chlorite. This adheres only to the crystal-edges of the augite, it is not found against the fractured edges. The fragments of crystal and glass alike are embedded in a groundmass, which consists of irresolvable, apparently partly felspathic decomposed matter, which seems to have been produced by the pulverisation of felspar-phenocrysts, together with fragments of pyroxene, chlorite, epidote, calcite, and rarely a little magnetite. This rock is best considered as a brecciated, hypocrystallite augite-porphyrite. (See Plate lii., fig. 2.)

### *Keratophyres.*

These are far less frequent in the massive condition than the spilites or the dolerites, though they are very abundant in the

pyroclastic rocks. The largest development is in the complex on Portion 175, Nemingha. They generally contain some quartz. Two types may be specially noted. Specimen 1140 resembles the rocks from Pipeclay Gully, near Bowling Alley Point(17). It is vesicular, with phenocrysts of albite, in a base of finer laths of felspar, and a small amount of quartz with chalcedonic margins. Chalcedony also occurs surrounding the grains of quartz. It is probably intermediate in composition between the porphyritic magnetite-keratophyres and the spilites. The first-named are the more coarsely crystalline. Their large phenocrysts are all albite, or are partly replaced by calcite, and a mosaic of minute prisms of albite; which certainly suggests the secondary nature of the albite. They are also dusted with other secondary material. There are, in addition, large octagonal areas of calcite and chlorite, which doubtless represent former phenocrysts of augite. A few of these have inclusions of felspar. The base consists of minute laths of acid plagioclase, chlorite, and magnetite, the latter occurring abundantly interstitially, and especially segregated about certain lines, as in 1148, and about the calcite-filled vesicles. Specimen 1361 differs from the others in the finer grainsize, and in the absence of phenocrysts of augite, and also in the presence of a large amount of black inclusions in the margins of the felspar-crystals, which inclusions, however, do not seem to be of primary origin, but to have been introduced from the magnetitic matrix, and lie in the cleavage-traces of the felspar, and in other definite directions in the crystals that are not marked by any noticeable cleavage. These two rocks also afford evidence of the pneumatolytic introduction of magnetite, in the later stages of their consolidation.

Magnetite-keratophyre also occurs in Portion 110, Nemingha, in the southern extension of the East Gap Hill zone, but as it has some fragmental characters, it is discussed below.

Some quartz-keratophyres remain for consideration. One of these (1142) occurs in Portion 138, adjacent to the magnetite-keratophyre of Portion 110. It is porphyritic, with phenocrysts of andesine which fill the numerous vesicles. Dusty hæmatite is

present in small amount. Specimen 1148 is a fine-grained, vesicular, purplish-grey rock, with small, clear phenocrysts of albite, one of which contains, in its central portion, abundant inclusions of dusty magnetite. These phenocrysts have a roughly trachytic arrangement. The groundmass consists of abundant minute felspar-laths, sprinkled with finely divided hæmatite. Quartz is present in some amount, often chalcedonic, and a little chlorite occurs. There are abundant large vesicles filled with calcite, and chlorite, or quartz and chlorite. There is often a dense segregation of dusty magnetite around the whole, or only a portion of the periphery of the vesicles, and one can see that the zone of vesicles that are most abundantly surrounded by magnetite, corresponds to a zone of enrichment by magnetite of the main mass of the rock, which lies on either side of a narrow crevice, running transversely to the flow-direction of the rock. This is clearly illustrated in the figure given (Plate lii., fig. 3). The presumption is that the magnetite in the rock has been partly, at least, introduced pneumatolytically, and that surrounding the vesicles is due entirely to this method of deposition. This is in accord with the results obtained from the study of the Hyde's Creek complex in the Nundle District(17).

Rather different types of rocks, which, however, are clearly related to the above, are represented by specimens 1360 and 1363, that occurred in association with the agglomerate in the complex illustrated by Text-fig. 13. They were termed spilite-porphyrites in the foregoing. The felspar-phenocrysts may reach 2 mm. in length, are dusty and spotted with chlorite, slightly zoned, and show pericline- as well as albite-twinning. The augite phenocrysts are also large, 3 mm. × 0·5 mm. at most, are fresh or more or less decomposed, and have a large optic axial angle ($2V = 52°$). Magnetite also occurs in large well-formed crystals. The groundmass consists of lathy andesine-oligoclase, quartz in sharply defined crystal-grains, and but rarely intersertal, granular augite, and skeletal ilmenite, with small vesicles filled with quartz, chalcedony,

opal and chlorite. This rock is on the borderline between the quartz-dolerite-porphyrites and keratophyres, and, like the adjacent dolerite proper, it has not been albitised.

A more typical keratophyre is that occurring near Gap Creek, half a mile east of this spot (1136). Its composition is shown by the analysis given on p.602. Its texture is very net-like; there is no sign of flow-structure, though the ragged felspar-laths sometimes give a sort of ophitic texture with the small amount of augite, with which they are associated. The latter is now mostly changed to chlorite. The felspar also forms small, interstitial, spherulitic aggregates. Quartz is very abundant, both interstitially and in small veins, but there are no chalcedonic phases. The composition of the felspar, as calculated from the analysis is $Or_8Ab_{80}An_{16}$, equivalent to $Ab_{84}An_{16}$.

In addition to this, there are a few occurrences of highly crushed quartz-albite-porphyrites, in Portions 168, 213, and 171, Nemingha. These consist (*e.g.*, 1326, 1332) of broken phenocrysts of albite (probably), with all the optical effects of great strain, and a groundmass of finely granular, and intergrown, strained quartz and albite. There is rarely also a little biotite in spangles and crystal-plates, wisps of fibrous, pale green actinolite, both in phenocrysts and base, and a little magnetite and titanomorphite. A similar rock occurs on the north side of Housefield's Hill, Woolomol, forming a vein in the Middle Devonian rocks. The whole appearance of these rocks strongly recalls that of the albitic veins in the serpentines near Bingara, and it is not clear whether they should really be classed with the Devonian keratophyres(**16**, p. 691).

### *Chemical Characters of the Spilite-Keratophyre Series.*

The chemical features of these rocks will be illustrated by the following table, which should be compared with the tables given in previous parts of the series (**16**, p.704; **17**, p.139).

CHEMICAL COMPOSITION OF MIDDLE DEVONIAN IGNEOUS ROCKS.

| | 1132 | 1130 | 1136 | A | B | C |
|---|---|---|---|---|---|---|
| $SiO_2$ .. ... | 49 96 | 50·17 | 71·52 | 72·51 | 56·06 | 52 88 |
| $Al_2O_3$ .. ... | 15·49 | 15·56 | 11·76 | 13·10 | 18·36 | 21·25 |
| $Fe_2O_3$ .. ... | 1·83 | 2·18 | 1·52 | 2·81 | 4·40 | 2·73 |
| FeO... .. ... | 10·85 | 12·06 | 3·44 | 0·90 | 2·68 | 3·02 |
| MgO .. .. | 4·70 | 3 49 | 1·18 | 0·20 | 4·58 | 4·93 |
| CaO .. .. | 8·52 | 7·77 | 2·72 | 1·84 | 6·06 | 7·40 |
| $Na_2O$ .. ... | 2·90 | 4·12 | 5·05 | 6·76 | 3·71 | 3·95 |
| $K_2O$ .. ... | 0 65 | 0·38 | 0·26 | 0·33 | 0·66 | 1·15 |
| $H_2O+$ .. ... | 2·47 | 1·12 | 1·25 | 0·35 | 2·50 | 2·53 |
| $H_2O-$ . ... | 0·04 | 0·27 | 0·14 | 0 04 | 0·28 | 0·25 |
| $CO_2$ . .. | 0·05 | 0·21 | 0·38 | 0·76 | 0·24 | 0·20 |
| $TiO_2$ . ... | 1·40 | 1·51 | 0 28 | 0·31 | — | — |
| $P_2O_5$ . .. | 0·38 | 0·18 | 0·20 | 0·06 | 0·19 | 0 29 |
| $FeS_2$ . | 0·10 | 0·10 | 0·12 | — | — | — |
| $Cr_2O_3$ . .. | abs. | abs. | abs. | — | — | — |
| MnO . .. | 0·14 | 0·43 | 0·04 | 0·20 | — | — |
| BaO . ... | abs. | abs. | abs. | abs. | — | — |
| SrO... .. . | abs. | abs. | abs. | — | — | — |
| | 99·48 | 99·55 | 99·86 | 100·17 | 99·72 | 100·58 |
| Analyst . | W.N.B. | W.N.B. | W.N.B. | Radley | Mingaye | White |

1132. Labradorite-dolerite, Portion 110, Parish of Nemingha.
1130. Albitic Spilite, Portion 48, Parish of Nemingha.
1136. Quartz-keratophyre, Portion 175, Parish of Nemingha.
A. Soda-granite-porphyry, Tayvallich, Argyllshire, Scotland(26).
B. Typical volcanic tuff, Tamworth(9).
C. Matrix of coarse volcanic agglomerate, Tamworth(9).

The discovery of calcic rocks in this area brings a feature into the discussion of the origin of the albitic rocks in this area, which was not present in the Nundle district; and some of the Tamworth rocks show the same microscopical features as those considered by various authors to indicate the secondary nature of albite in rocks of the spilitic suite, which features were not observable in the rocks described previously(17). As investigations are now in progress in the region between the Tamworth and Nundle districts, the further discussion of this question will be postponed till it be finished.*

* The writer has received, too late for consideration in the present paper, Dr. Nils Sundius' work, which deals with this problem. Geologie des Kirunagebiets. 4. Beiträge zur Geologie des südlichen Teils des Kirunagebiets. Vetenskapliga och Praktiska Undersökningar i Lappland. Anordnade af Luossavaara-Kirunavaara Aktiebolag. (Scientific and Practical Researches in Lappland, arranged by the Luossavaara-Kiirunavaara Aktiebolag.) Upsala, 1915.

*Pyroclastic Rocks.*

It is in this division of the igneous rocks, that the greatest difficulty arises, for they range from types scarcely separable from the normal massive rocks to those which are clearly tuffs, and agglomerates that closely resemble conglomerates. They also have a wide range of composition, corresponding to the range of variation in the massive rocks, and may include fragments of all the known types of massive rocks, as well as others, which have not been found forming separate masses; they may contain also fragments of all types of sedimentary rock in the district. This naturally makes a logical sequence in the description of these rocks almost an impossibility. It seems, therefore, best to divide between pyroclastic masses that are referable to one igneous type only, and those of a mixed composition. The latter can be divided according to their coarseness of fabric. Of these, some of the most coarsely fragmental types have rounded inclusions resembling boulders in conglomerates.

Of the rocks composed of a single type of material, we may, perhaps, take as an instance the augite-porphyrite breccia already described. It certainly is a passage-rock of a nature between massive and fragmental. A similar passage-rock is the spilite-breccia, which lies on the margin of the spilite-dolerite mass at Tintinhull. This rock consists of more or less fragmental phenocrysts of albite, set in a very fine matrix of the same character as that of the adjacent porphyritic spilite(1171). The brecciated quartz-keratophyres should also be mentioned here. Types occur, particularly in Portion 183, Nemingha, on West Gap Hill, which are even more fragmental than the highly strained keratophyres mentioned above. They have a grey quartzite-like appearance, and show small crystals of felspar, and have a more or less well marked bending. They consist of crystals of albite, irregular corroded quartz-grains, and sometimes fragments of a very fine-grained trachytic keratophyre, and aggregates of quartz and magnetite, drawn out into the general direction of the banding. The groundmass consists of the same material very finely divided. It is possible that these are flow-breccias(1052, 1125).

The pyroclastic rocks of the Igneous Zone on East Gap Hill extend down to Portion 138, and near their southern extremity, in Portion 110, is the fragmental magnetite-keratophyre mentioned above(1122). It, also, is possibly a flow-breccia. It is extremely patchy in constitution; adjacent portions are of different composition and texture; and the types of texture seen are usually different from those which are present in the magnetite-keratophyre-breccias at Hyde's Creek, near Bowling Alley Point. The groundmass of the rock is very like a sponge. The "sponge"-fabric is made up of fine laths of albite, clouded by kaolin, etc., and so darkened with abundant masses of minutely divided magnetite, that it is almost opaque. The interstices are filled with minute prisms of glassy albite, generally twinned, and accompanied by a little chlorite. Set in this matrix, are fragments of dense trachytic magnetite-keratophyre, with phenocrysts of albite and sometimes of fresh augite, and, in addition, there are fragments of normal trachytic keratophyre, with very little magnetite or augite. These inclusions vary from very minutely to coarsely crystalline types, and the latter may even be sufficiently rich in augite, to be classed as dolerites (Plate lii., fig. 4). A large vesicle present in the rock has been filled by a spongy mixture of albite and calcite. There can be little doubt that this rock has been affected by pneumatolytic solutions, which introduced the sodic felspar. The abundance of hæmatite, which gives the dominant red colour to the ferruginous pryoclastic rocks at the southern end of East Gap Hill, is probably also due to the action of these solutions, which have oxidised the magnetite in the magnetite-keratophyres. In those ferruginous keratophyres in which the iron ore seems to be of secondary, pneumatolytic origin, it is possible that the ore was deposited in the rock, in part at least, as hæmatite. In those, however, in which the majority of the iron occurs as magnetite, the dark grey colour is the characteristic feature. Of these, Specimen 1178 is typical. It has some macroscopical resemblance to 1122, but has very little groundmass. It consists of fragments of keratophyre, of which twelve different samples are to be found in a slice scarcely two square centimetres in area. These are closely fitted together, with a little cement made

of the material of the fragments finely comminuted. The following are the chief types of fragments present:—magnetite-keratophyres, varying in the amount of iron present, more or less trachytic, porphyritic, massive or hypocrystalline, the last being very vesicular; normal keratophyre, porphyritic or massive, trachytic, or with a wavy flow-structure and occasionally vesicular, coarsely crystalline albitite, partially porphyritic keratophyre-dolerite, etc.

The reddened rocks have usually a more ashy appearance, particularly on weathered surfaces. In 1330, the inclusions are mostly fine-grained trachytic keratophyre, with minutely granular augite, and a few more coarsely granular, non-trachytic types are also present. The base resembles that of 1122; it is very spongy, with a few phenocrysts of albite, and abundant secondary albite and chlorite filling the vesicles. In 1336, the same feature are present, but parts of the spongy or pumiceous matrix are free from iron-ore, but shade off irregularly into strongly ferruginous rock.

Hæmatitic breccias similar to these, but much more coarsely fragmental, occur on West Gap Hill. In these, there are large areas of finely divided prehnite and epidote. The matrix is rather spongy, a hypocrystalline confusion of felspar-laths, phenocrysts, and microlites, and abundant hæmatite. The inclusions are of various kinds of keratophyre; the most unusual of these has a texture resembling that of "rhomben porphyry"; the others resemble those already described.

In addition to the red rocks of this character, there are others in which there is no base. The rocks consist entirely of fragments, which are sometimes half an inch in diameter, and are closely fitted together. These (*e.g.*, 1327) include keratophyre; prophyrite consisting of large rounded phenocrysts of acid plagioclase in a fine-grained subtrachytic base, in which are chlorite-filled vesicles; porphyritic spilite, the felspar albite, and the augite changed to chlorite; devitrified rhyolite with a well marked flow-structure; magnetite-keratophyre of varying character, sometimes extremely rich in iron-ore, sometimes porphyritic with crushed and shattered phenocrysts; and felsites with a minutely crystalline or lithoidal

base abundantly charged with calcite, or a more coarsely granular quartz-felspar mosaic, apparently greatly strained. It is, however, just possible that the last two fragments are of altered sedimentary rock.

Rocks similar to these, but with rather smaller grainsize, form the bulk of the Igneous Zone of the Middle Devonian, that sweeps northwards to Moore Creek. They resemble the "Bowling Alley breccias," of the earlier papers, with which they must assuredly be correlated (**16**, p.710-711). An example of these rocks, showing a more diverse composition than usual, is illustrated in Plate liii., fig. 6, which is from slide 1163, from a rock which accompanies the porphyritic spilites in Portion 48, Nemingha. It consists of single crystals and rock-fragments. The former include quartz, uralite, and acid felspar; the latter range from spilites resembling the base of the adjacent porphyritic spilite, to more crystalline trachytic spilites, fine- and medium-grained keratophyres; quartz-keratophyre; quartz-porphyrite; and a soda-granophyre. In addition, there is a fragment of radiolarian mudstone. There is practically no groundmass. The metamorphic effect of the granites, which are exposed within half a mile of here, is seen in the development of abundant little flakes of secondary biotite in the fragments of keratophyre.

Other rocks in this zone differ from this in the presence of fragments of dolerite, of more sedimentary rocks, and sometimes of limestone, or in the presence of crystals of augite or magnetite In others, again, more groundmass is present, generally finely divided quartz, and felspar, with more or less chlorite. These are only differences of degree; no distinct varieties of pyroclastic rock can be separated. In the most finely granular of these rocks, the fragments are usually merely portions of single crystals, or of very minutely crystalline keratophyre. They have often a more abundant base of comminuted quartz and felspar, and, while they are generally unstratified, bedding is at times very clearly marked. Some of the pyroclastic rocks contain very well preserved radiolaria(**10**). The felspar is usually albite. In one instance only has hypersthene been observed in these rocks. As a rule, the pre-

sence of stratification and of organic remains are the only means of distinguishing, in *hand-specimen or microscope-slide,* an interstratified from an intrusive tuff.

All along the margin of the granite, these rocks are found to be more or less altered. This metamorphism has been described in general terms in a previous paper(16), and very little additional information has been obtained from the present more detailed study. Generally, the effect has been to convert all the ferromagnesian minerals present into actinolite, which may be scattered all over the rock in secondary sheaf-like recrystallisations. The ilmenite becomes titanomorphite, and the plagioclase, clear albite, which may be more or less crystalloblastic. In more altered rocks, the felspar returns to andesine, which has been found in several instances, particularly in Portion 118, Nemingha. This accords with the behaviour of the spilitic rocks about the granites of Devonshire(**27**). Erdmannsdörfer concludes, from his study of the diabases about the granite of the Harz Mountains, that, whereas the presence of basic felspar is an index that the rock has suffered contact-metamorphism, types with acid felspar result from dynamic metamorphism(**28**, p.73); this conclusion cannot, however, be applied satisfactorily to the rocks of the Tamworth district.

The most altered forms of spilitic rocks are those in Sections 113 and 123, Nemingha. Macroscopically, they are very like the garnet-bearing contact-altered spilites of Walkhampton in Devonshire, which were described by Messrs. Dewey and Flett(**27**) They are banded dark green rocks, with long lenticular patches of quartz and felspar mosaic, probably representing former felspar-phenocrysts, and long bands of epidote and brown garnet, together with a little secondary acid felspar. The dark base consists of very finely matted chlorite and actinolite, while there are also streaks of secondary magnetite. It is not clear whether these are altered vesicular, porphyritic spilites, or pyroclastic rocks. The former is the more probable. Adjacent to these, is the amphibolite (altered dolerite) described above.

Other types of rock occur, of which a few examples will suffice. A rock (1134), which occurs in Portion 173, Tamworth, is an

altered breccia, made up of many differing portions, each uniform within itself. The more finely granular fragments consist of small short prisms of hornblende with a roughly parallel arrangement, in a groundmass of small, equant, untwinned grains of quartz, and (probably) andesine; occasionally, there are large, irregular plates of an indeterminable felspar. Surrounding each such fragment is a zone of larger crystals of hornblende, among which are frequently small patches of fresh, new-formed, colourless pyroxene, making irregular poikiloblastic plates. These have very oblique extinction, and a large optic axial angle. Rarely there are also poikiloblasts of hornblende. In the irregular groundmass between the fragments, there are also irregular prismoids of hornblende, granular and poikiloblastic secondary augite, poikiloblastic, dusty, twinned plagioclase, and abundant, usually untwinned oligoclase-andesine(?) in the matrix. Rarely, also, there are poikiloblasts of quartz that are quite free from strain-effects. Magnetite is scattered about.

Slide 1137, from the same locality, differs from 1134 in the presence of large porphyroblasts of andesine. The secondary augite at times shows a sieve-structure, but more usually forms solid grains, or scattered granules. Erdmannsdörfer has described the development of secondary enstatite in the altered diabases by the granite of the Harz(**28**, pp.17-19). The pyroxene in the rocks just described, though it is augite, seems also to be secondary; it is certainly not residual, and as it occurs only in rocks quite close to the granite, it is probably developed under the effects of contact-metamorphism. Erdmannsdörfer observes that the degree of metamorphism necessary to produce secondary pyroxene is greater than that necessary for the change of augite into fibrous amphibole(**28**, p.37); the present rocks seem to exemplify this conclusion.

In the altered limestone of Seven-Mile Creek, is a green felspathic rock (1372), which is probably an altered pyroclastic inclusion. It consist of large poikiloblastic grains of andesine, dotted with small grains of diopside, here and there aggregated into dense masses. Scattered about there is also sphene in irregu-

lar grains. A small amount of quartz occurs with the felspar, but iron-ores are not developed.

A very special form of pyroclastic rock is the agglomerate which occurs in Portion 162, Nemingha. As described above, this rock contains a number of rounded pebbles of igneous rock in a tuffaceous matrix. Though several types of rock appear to be represented among the pebbles on macroscopic examination, the miscroscope shows them to be mostly of one type in different stages of alteration. They are porphyrites, with phenocrysts of plagioclase, more or less decomposed, slightly zoned, and, for the most part, determinable as oligoclase. In some of these, the former zoning is strongly marked by the presence of kaolin or dusty matter, though optical tests show the crystal to be of uniform acid composition (cf.29, p723). Augite also forms phenocrysts, but is more or less chloritised, and has a strongly marked outer margin of magnetite. There are smaller phenocrysts of magnetite, and corroded quartz, lying in a very fine-grained felsitic base. In addition, there is a porphyritic spilite, with phenocrysts of albite, in a pilotaxitic to subvariolitic groundmass of albite-laths, with chlorite, ilmenite, magnetite, and titanomorphite. Sometimes there are vesicles filled with calcite. One of these rocks is very similar to the spilite of Tintinhull, or of the Eastern Series. Another rock(1355) has a rhyolitic appearance, but is quite holocrystalline, and very finely granular. Its composition is that of a magnetite-keratophyre. There are idiomorphic or slightly corroded phenocrysts of acid felspar, and a few large accretions of minutely granular magnetite, and glomero-porphyritic quartz-felspar aggregates. The groundmass is made up of trachytic microlites of felspar, dotted with dusty magnetite, and interspersed with rounded felspar-crystals, which are not really spherulites, as their appearance suggests. These are arranged in bands, and thus give the rhyolitic appearance to the rock. The matrix of this rock is composed of crystals and fragments apparently derived from the porphyrites, which form the most abundant inclusions.

The pyroclastic rocks in the Upper Middle Devonian Series are similar to those in the Lower Middle Devonian, but are generally

more finely granular. The chief distinction, however, lies in the greater abundance of quartz and acid felspar in the newer rocks, fragments of cryptocrystalline and trachytic keratophyre being very common. In addition to this, there is an abundance of purely keratophyric material, which forms the white interlaminations in the claystones; these vary in thickness from some yards down to fractions of a millimetre. Sometimes they have a flat lower side when they have fallen on to partially consolidated clay, or the underside may be indented where the falling grains sank into soft silt. The upper side is quite irregular in both cases (see Plate liii., fig. 7). Such interstratified tuffs may contain radiolaria or plant stems. Intrusions of keratophyric tuff into the sediments are frequently observable under the microscope, a particularly clear instance being that shown in Plate liii., fig. 8. Fig. 9 of the same plate illustrates a clearly clastic rock, which is similar in all respects to the intrusive material in the specimen shown in Fig.8.

The general character of the Upper Middle Devonian and Upper Devonian pyroclastic rocks has been described thus:—"At some depth below the surface the colour of the tuff is greenish-grey, weathering to yellowish-brown or lighter grey at the surface, and thus contrasting strongly with the darker claystones. A chemical analysis of the tuff will be found on p.602. Mr. Card describes them as felsite-tuffs, with numerous fragments of cryptocrystalline felsite (Keratophyre, W.N.B.) entangled in the holocrystalline or microcrystalline groundmass. The latter is composed of broken or corroded crystals of plagioclase, orthoclase, quartz, and augite, with occasionally hornblende, and rarely sphene" (titanomorphite, W.N.B.). "Small crystals of iron pyrites are numerous and grains of titaniferous iron sometimes occur; small and large inclusions of radiolarian rocks abound."(9). The fragments of radiolarian rock in the tuff are often very rounded (see Text-fig. 10), and there is some alteration of the tuff about them. Numerous instances occur in which the inclusion is ringed around by a pinkish-white zone, which is very distinct macroscopically. Under the micro-

scope, however, nothing definite can be learnt as to its nature, and frequently it is not recognisable except in hand-specimen. At other times, there appears to be a slightly greater amount of kaolinisation, and the development of a little prehnite. It is evidently due to some radial diffusion, but does not appear to be connected with any process of albitisation. Prehnite is quite frequently developed in tuffs in patches that are not directly associated with cherty inclusions. So far as can be ascertained, the felspar in these pyroclastic rocks is almost entirely acid; no grain has been noted, of which the refractive index is greater than that of Canada balsam. The analysis (B., p 602) does not indicate any great amount of soda, and the composition of the felspar calculated therefrom is that of labradorite. The entry of alumina into various decomposition-products, probably accounts for the difference between the calculated and observed compositions of the felspar.

*Limestones.*

The macroscopic features of the limestones of this district have already been described The following analyses illustrate their chemical composition. These were made by the chemists of the Geological Survey, for a memoir on the limestones of New South Wales, now being prepared by Messrs. J. E. Carne and L. J. Jones. The writer is much indebted to Mr. Carne for his kind permission to use them. Assays 1645-6 were specially made by Mr. Mingaye from specimens chosen by the author.

| Assay No ... | 1146 | 1147 | 1394 | 1145 | 1148 | 1149 |
|---|---|---|---|---|---|---|
| $CaCO_3$ .. | 92·77 | 93 07 | 98·85 | 98·70 | 96·76 | 92·82 |
| $MgCO_3$ ... | 0·89 | 0 75 | 0·42 | 0·25 | 0·71 | 0·69 |
| $MnCO_3$ .. | 0·16 | 0·14 | 0·04 | 0·02 | 0 04 | 0·06 |
| $Fe,Al_2O_3$ .. | 0·42 | 0·40 | 0·22 | 0·19 | 0·33 | 0 28 |
| Gangue .. | 5·98 | 5·72 | 0·64 | 1·20 | 1·88 | 5 72 |
| | 100·22 | 100·08 | 100 17 | 100·36 | 99·72 | 99·57 |

| Assay. | $CaCO_3$ | $MgCO_3$ | $FeCO_3$ | $MnCO_3$ | $Fe_2O_3$ | $Al_2O_3$ | Gangue | $P_2O_5$ | $H_2O$ | $BaCO_3$ | *$SrCO_3$ | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1645 | 98·14 | 0·09 | 0·05 | 0·11 | 0·22 | nil | 0·98 | 0·03 | 0 58 | nil | tr. | 100·20 |
| 1646 | 97·42 | 0·04 | 0·04 | 0·04 | 0·44 | 0·09 | 1·62 | 0·02 | 0·36 | nil | tr. | 100·08 |

* Spectroscopic test.

These samples came from the following localities:—

Nemingha limestone.

1146. Portion 118, Nemingha.

1147. Portion 63, Nemingha (formerly Beedle's Freehold).

1645. White marble, Portion 134, Nemingha.

1646. Red marble, Portion 134, Nemingha, (known as the "Nemingha red marble").

Loomberah limestone(?).

1395. Portion 121, Nemingha.

Moore Creek limestone.

1145. Portion 41, Woolomol.

1148. Municipal Quarry, Spring Creek, Tamworth.

1149. Reserve 1472, Woolomol.

It will be seen that the rocks, as a whole, are very free from dolomitisation, and that the limestones of the Nemingha horizon differ from those of the Moore Creek horizon in the slightly greater content of iron, alumina, magnesia, and manganese. This is probably due to their association with igneous rocks, particularly the ferruginous brecciated keratophyres. It is clear that the intrusion of the ferruginous keratophyres was accompanied by the emission of iron-bearing solutions (17, pp.14-15). A red colour is a frequent feature of the limestones of this horizon.

The description of the radiolarian limestone given by the previous authors(9, 10) need not be supplemented here. Mr. Mingaye's analysis of this rock is cited below.

Around the margin of the granite, the limestones have suffered much alteration. This was briefly described in an earlier paper(16), and also in the paper by Messrs. David and Pittman(9). A number of additional slices made subsequently, have added but little to the information here given. The pyroxene developed seems, however, to be a green variety of diopside rather than omphacite. One new type of rock has been discovered in the northern, sharply bent anticline, in Seven-Mile Creek. It consists almost entirely of silky-white wollastonite. Its interstices contain diopside, calcite, and a doubly refracting garnet. In another sample, diopside and garnet predominate over the wollastonite, and the garnet forms aggregates, half an inch in diameter. A third rock contains a little scapolite.

### *Middle Devonian Cherts and Claystones.*

The sedimentary rocks of the Middle Devonian Series have few features of petrological interest. The general characters were described by Messrs. David, Pittman, and Card(9), and the writer(16). Here and there, they are enriched with tuffaceous matter, where zones of larger grainsize composed of fragments of quartz, felspar, or cryptocrystalline felsite, are interstratified with the normal claystone, into which they gradually shade away. In none of the rocks which the writer has studied microscopically, has he been able to recognise the presence of minerals which ordinarily characterise contact-metamorphism, nor does it appear probable that they would be developed, if the intrusions of the pyroclastic material took place in the manner here described, which would involve an intrusion at a fairly low temperature.

Considerably altered rocks occur about the granite; the most intensely altered are those actually included in the granite in Portion 66, Tamworth. These have abundantly developed biotite, and are interleaved with narrow bands of pegmatite, and granite. A less altered type (1133) is a fine-grained quartz-schist, with minute, chloritised flakes of biotite, and fragments of orthoclase and andesine.

The chemical composition of the sedimentary rocks will be seen in the table herewith, of analyses by Mr. Mingaye(9).

| Assay number ('97)... | 1234 | 1236 | 1235 | 1233 |
|---|---|---|---|---|
| $SiO_2$ | 91·06 | 80·50 | 67·87 | 18·05 |
| $Al_2O_3$ | 3·79 | 9·57 | 15·25 | 3·49 |
| $Fe_2O_3$ | 2·01 | 2·67 | 5·08 | 4·87 |
| $MgO$ | 0·46 | 0·76 | 1·46 | 1·65 |
| $CaO$ | 0·45 | 0·60 | 1·71 | 38·70 |
| $Na_2O$ | 0·28 | 1·18 | 1·37 | 0·29 |
| $K_2O$ | 0·84 | 1·68 | 2·21 | 0·44 |
| $H_2O$ | 0·97 | 1·29 | 2·10 | 1·42 |
| $H_2O-$ | 0·32 | 0·45 | 2·37 | 0·80 |
| $CO_2$ | — | — | abs. | 30·15 |
| $P_2O_5$ | tr. | 0·11 | 0·12 | 0·34 |
| $SO_3$ | 0·35 | tr. | tr. | tr. |
| $FeS_2$ | — | — | — | 0·24 |
| $MnO$ | tr. | tr. | tr. | tr. |
| Organic matter | tr. | 0·86 | — | tr. |
| | 100·53 | 99·67 | 99·54 | 100·44 |

| | |
|---|---|
| 1234. Radiolarian black chert. <br> 1236. Radiolarian cherty shale. | The exact points at which these rocks were collected are not stated. |
| 1235. Radiolarian shale. <br> 1233. Radiolarian limestone | They all came from the neighbourhood of the Tamworth Common. |

### *Upper Devonian Baldwin Agglomerate.*

Messrs. David and Pittman have pointed out that the matrix of the agglomerate occurring on Cleary's Hill, near Tamworth, is identical with the breccias of the Middle Devonian Series(9). The writer has shown that this is a part of the Baldwin Agglomerates, and that this similarity is a constant feature; indeed, the agglomerates may be described as an "exaggeration of the features of the breccias of the Tamworth Series," and when they take on a rather finer grainsize than usual, it is impossible to distinguish them from the Middle Devonian rocks. At certain points they are full of rounded boulders, which decrease in size as the strata are traced laterally. Each centre has about the same assortment of boulders, though differences occur. The boulders in the agglomerates at Cleary's Hill include the following:—Porphyritic dolerite, with phenocrysts of albite and augite, and a subvariolitic base; porphyritic spilite, with felspar-phenocrysts and minutely crystalline trachytic base; felspathic dolerite; porphyritic andesite, as described by Mr. Card(9, p.36), in which the augite has the peculiar brownish tint and appearance characteristic of the brecciated augite-porphyrite described above (p.598); with decreasing amount of ferromagnesian minerals, these dolerites pass into keratophyres, sometimes porphyritic, but with a beautifully trachytic base (a very common rock), or the base may be felsitic or cryptocrystalline; one example is orthophyric and has no phenocrysts. There is also a quartz-keratophyre, the phenocrysts of which are more or less corroded quartz and albite, and the cryptocrystalline base contains long patches of fibrous radiating felspar, and also fragments of magnetite-keratophyre. In addition, there are fragments of previously consolidated tuff, of limestone, and of chert. The matrix consists chiefly of fragments of felspar, often zoned andesine, but also albite, quartz, augite, ilmenite, and a still more minutely comminuted paste of these minerals, with calcite, chlorite, etc. The chemical composition of the matrix has been determined by Mr. White. (See C, p.602).

The agglomerate of Housefield's Hill, in the centre of the Parish of Woolomol, contains approximately the same variety of boulders. The peculiar strained quartz-keratophyre is found also as a dyke beside the hill. The waterworn appearance of the pebbles and boulders is especially marked in this locality.

*Serpentines.*

The majority of the serpentines seen are similar to the rocks described in the earlier paper(**16**), and do not call for any further comment. One specimen, however, from Portion 118, Parish of Nemingha, is of special interest. It is a typical example of a serpentine derived from diallage The chief constituent of the rock is antigorite, which in some places exhibits the "gitter-struktur" perfectly, but is more usually distributed rather irregularly, or grouped into radiating masses. Some residual diallage is present, into which the antigorite cuts sharply, either as irregularly placed blades, or in lines parallel to a cleavage. The last remnants of the diallage are cloudy grey matter. Small ribbon-like veins and irregular patches of fibrous anthophyllite(?) are also present, sometimes stained brown and matted, but never notably pleochroic. The anthophyllite-fibres may stretch across the whole width of the vein, or may grow out unevenly on either side of a narrow crevice. Very irregularly shaped masses of magnetite are scattered about.

Associated with the serpentine is a little gabbro, which has also been described; it is remarkable for the replacement of its felspar by zoisite. One specimen contained olivine and hypersthene, two minerals which are rarely seen in the gabbros in the Great Serpentine Belt. (See **16**, pp.683-4).

*Dykes of Dolerite in the Serpentine.*

A number of these have been studied, and found to correspond exactly with those described from the north side of Chrome Hill, Bowling Alley Point, of which an analysis has been made (**17**, p.139). According to the extent of the development of brown hornblende, the rocks may be classed as dolerites, with little hornblende, and proterobases, in which it is more abundant. The hornblende, however, is always subordinate to the augite,

and frequently surrounds this mineral. The felspar is difficult of determination, but it seems to be sometimes oligoclase, sometimes andesine. The ilmenite is usually represented by titanomorphite. Some sheared varieties of dolerite occur in which saussuritised felspar alternates with streaks of tremolite.

*Granite.*

The granite has been described by Mr. Card as follows:—
"6665. Moonbi, close to the railway station. Not conspicuously porphyritic. Sphene readily visible. The quartz is crowded with cavities. Hornblende and magnetite are intimately associated in places, and, together with felspar, give rise by segregation to basic patches. Orthoclase and plagioclase are present. The plagioclase may contain many foreign inclusions, and may show good composition zoning; it appears to be a variety of oligoclase. Sphene is conspicuous, and shows some intergrowth with hornblende.

3728. Moonbi Tobacco Farm. This type is decidedly dioritic, and differs much from that above described. It is non-porphyritic. Sphene is abundant and can be readily obtained (sometimes in well formed crystals) by washing the crumbling material under water. Under the microscope, one of the dominant minerals is hornblende; biotite is scarce. The hornblende is deep green in colour for the most part. It is more or less automorphic, and well cleaved. Sphene is plentiful. There is a little quartz, and practically no plagioclase. Orthoclase is perhaps somewhat larger in quantity than the combined ferromagnesian silicates. The leucocratic constituents are plentifully traversed by highly elongated, colourless, transparent rods. As a handspecimen, this rock would be classed as a quartz-syenite." (12).

Sections examined by the writer show similar features to those recorded above, but, in general, orthoclase does not seem to be so abundant as there indicated.

The numerous dykes of pegmatite and aplite have not been subjected to microscopical examination.

The more basic dykes show interesting features; the following may be recorded :—

1303. A dark vein in granite in Portion 114, Nemingha. This consists of a fabric of short laths, and less regular grains of plagioclase and orthoclase with interstitial quartz. A few corroded xenocrysts of the two felspars and quartz are also present; the last is very distinct from the groundmass, and is surrounded by a reaction-ring. In addition, there are abundant fresh grains of augite and platy ilmenite. The rock may be termed a micro-monzonite, or monzonite-aplite.

1308. A vein in Portion 145, Nemingha. This is also a micro-monzonite, but is of a different character. The felspars are larger, more irregular, and partially interlocking. The augite has been replaced by hornblende, and some sphene is present.

1174. A vein in the granite in Portion 73, Moonbi. This is very similar to 1308, but differs in presence of a groundmass of small felspar-laths, and small crystals of hornblende, and rarely a flake of biotite. The felspar seems to be chiefly plagioclase. The rock may be termed a micro-diorite or a diorite-aplite.

1175. A vein in the granite in Portion 139, Moonbi. This is the most unusual rock. It is a minette with spheroidal inclusions, rather different from the "Kugelminette" of the Odenwald and elsewhere(30). The rock consists of crystals of brown, almost uniaxial biotite in idiomorphic plates, idiomorphic augite, and magnetite, in a finely granular, felsitic matrix, dotted with minute crystals of magnetite, and a few minute prisms of apatite. The spherules are about 2-3 mm. in diameter. They consist of fibrous radiating felspar, with a little quartz in the central parts. Included in these are large crystals of diopside and biotite, which, in one instance, are in completely parallel intergrowth with each other. A little magnetite is dotted about. There is no bounding zone of coloured minerals marking the outline of the spherules. There are, in addition, druses with an angular, irregular outline surrounded by a "fence" of diopside-prisms, directed radially inwards, followed within by an irregular zone of untwinned felspar, with a central quartz-felspar mosaic. The inner zone is dotted with diopside and magnetite.

*Tertiary Basalt.*

The basalt is extremely fresh. It consists of small laths of labradorite, slightly zoned, granules of augite, large prismoid, but not idiomorphic grains of olivine, and small irregular grains and aggregates of ilmenite. There is a vesicle about 2 mm. in in diameter, the structure of which is shown in Text-fig. 15. All round the vesicle is a thick zone of minutely granular augite,

A B

Fig. 15.—A. Amygdule in Tertiary basalt(1164). Upper and middle portion opal, lower natrolite. The first and last of these contain prisms of augite. B. Spherule of augite-prisms in the same rock as A.

but within are comparatively large idiomorphic prisms of augite, of the same character as that in the groundmass of the rock, but lying more or less isolated in a matrix of opal and natrolite. The prisms are particularly well formed in the opal. The determination of this mineral is rendered certain by the very clear evidence of Becke's line, which shows that the colourless isotropic mineral has a distinctly lower refractive index than the natrolite. It is quite clear, and crossed by irregular cracks, without any sign of cleavage, such as analcite might show. There can be

little doubt that the vesicle was filled with magmatic water. It would seem that the jelly-like mother-liquor in the vesicles permitted the growth of well formed prisms of augite, which were pushed aside by the growing and mutually interfering spherical masses of natrolite and opal, in the outer portion of which the augites become imbedded. The growth of large idiomorphic crystals of ferromagnesian minerals in the concentrations of the residual magmatic water is analogous in some respects to the formation of barkevicite in the analcitic lugarites of the Glasgow district described by Tyrrell(31). It is also interesting as affording a good instance of the primary nature of a zeolite, upon which subject a considerable literature has accumulated in recent years. [See *e.g.*, Mr. Harker's Presidential Address(32), and the article (and bibliography) by Koenigsberger(33)]. Beside the vesicles, there are small veins and irregular patches of opal and natrolite, and a little radiating aggregate of augite illustrated in Text-fig. 15B. In addition to these, there are also present a xenolith of olivine, augite, anorthite, and picotite, and isolated grains of the same minerals. Such xenoliths and xenocrysts are commonly present in the Tertiary and Recent basalts throughout the world.

## SUMMARY.

The main results of the present work may be stated thus. A more detailed map has been made of the Tamworth district, than that given by the previous authors who studied the district, and the subdivision of the Devonian Series instituted elsewhere in the Serpentine Belt has been applied, with amplifications, to this district. The result has been a general confirmation of the earlier work, with some modification in the details. The history of the area was apparently as follows. In Devonian times, a series of radiolarian claystones was deposited on a steadily sinking sea-floor, which was maintained at a fairly shallow depth. During this period, there were great developments of volcanic activity, producing large amounts of pyroclastic matter, building masses of tuff and agglomerate, which, here and there, may have risen above the surface of the sea, as small, short-lived islands. There were two main

periods of activity, the first of which was also marked by the intrusion of massive and brecciated spilites, dolerites, and keratophyres. Peculiar types of intrusive tuffs were constantly developed, and their probable mode of origin is here discussed. At two or three epochs, limestones were formed, and the fossil-content of these is sufficiently varied to permit of their distinction on palæontological grounds. The total thickness of the series cannot be exactly determined, owing to the presence of an indefinite amount of faulting. An apparent thickness of over 12,000 feet of strata are of Middle and Upper Devonian age. Folding and faulting occurred probably in Carboniferous times. The movements were most pronounced along an axis running N.N.W.-S.S.E., but there is clear evidence of less important movements along a N.E.-S.W. axis. The folding was followed by the intrusion of peridotite, succeeded by that of a mass of granite, which produced interesting contact-metamorphism of the tuffs and limestones. No further events are recorded until the eruption of a small amount of basalt, probably during the Tertiary period. The discussion of the physiography is reserved for a future occasion.

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## EXPLANATION OF PLATES XLIX.-LIII.

### Plate xlix.

Topographical Map of the Tamworth District, plotted from a plane-table survey, with contour-lines based on aneroid observations.

### Plate l.

Geological Map of the Tamworth District.

### Plate li.

Geological Sections along certain lines through the Tamworth District. The vertical and horizontal scale is the same.

### Plate lii.

Fig. 1.—Sheared keratophyre from the Eastern Series (1305); × 16.
Fig. 2.—Brecciated hypocrystalline augite-porphyrite (1303); × 13.

Fig.3.—Magnetite-keratophyre with secondarily introduced magnetite (1148); × 13.

Fig.4.—Magnetite-keratophyre-breccia with inclusions of dolerite (1122); × 13.

Fig.5.—Breccia of various types of keratophyre, dolerite, spilite, and chert (1355); × 13.

Plate liii.

Fig.6.—Similar to Plate lii., fig.5, but with large grains of quartz (1163); × 17.

Fig.7.—Crystals of felspar and fragments of microcryptocrystalline keratophyre in radiolarian mudstone (N S.W.G.S. 627); × 17.

Fig.8.—Intrusion of felspathic tuff into radiolarian mudstone. The clear, colourless casts of radiolaria can be seen in abundance (N.S.W. Geol. Survey, 1190); × 2.

Fig. 9.—Felspathic tuff of the same character as that in Fig.8; × 16 (approx.). Polarised light.

Fig.10,—Intrusion of breccia into banded tuffaceous mudstone; one-half natural size. See Text-fig 5.

## *Corrigenda to Part iv. (this Volume), pp.121-170.*

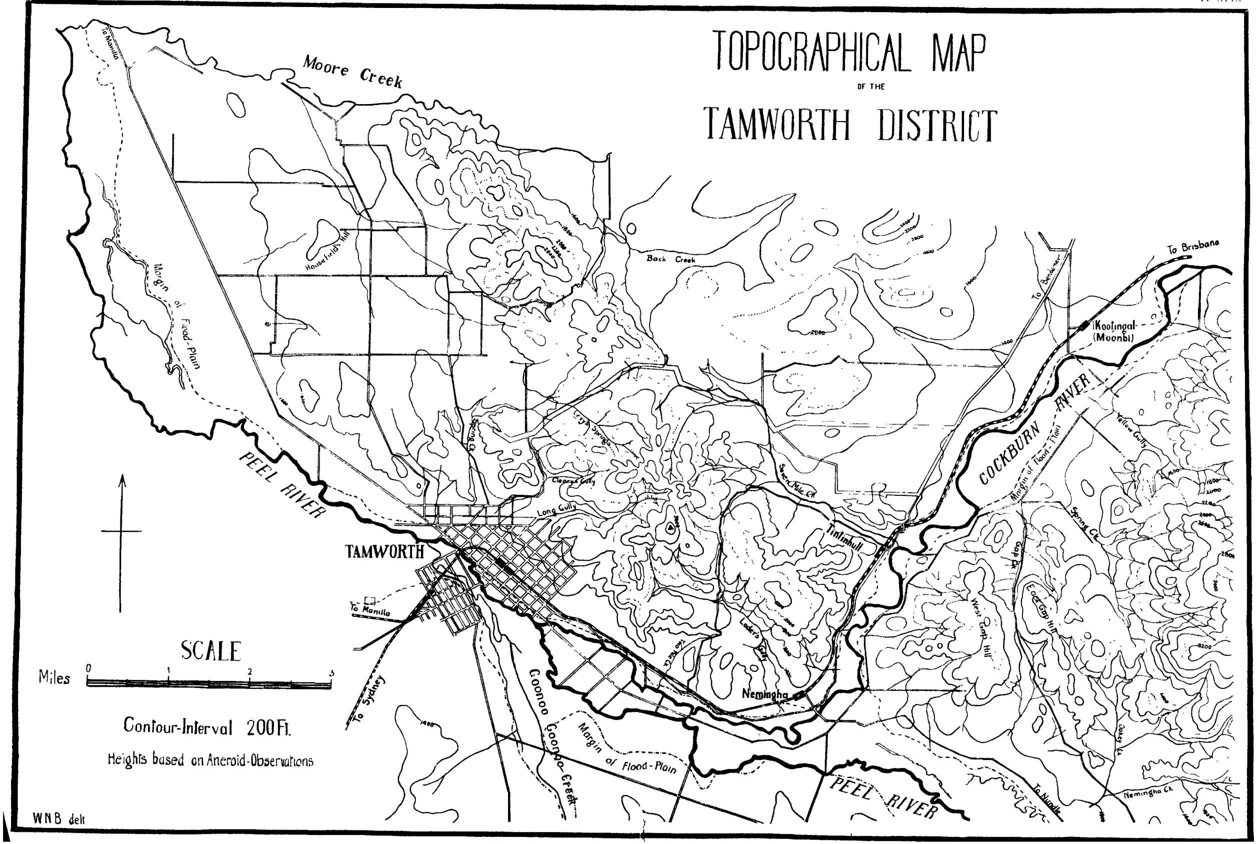
Page 127.—*for* "Text-fig.1. Spilite intrusive into radolarian clay." *read*, "Spilite intermingled with chert."

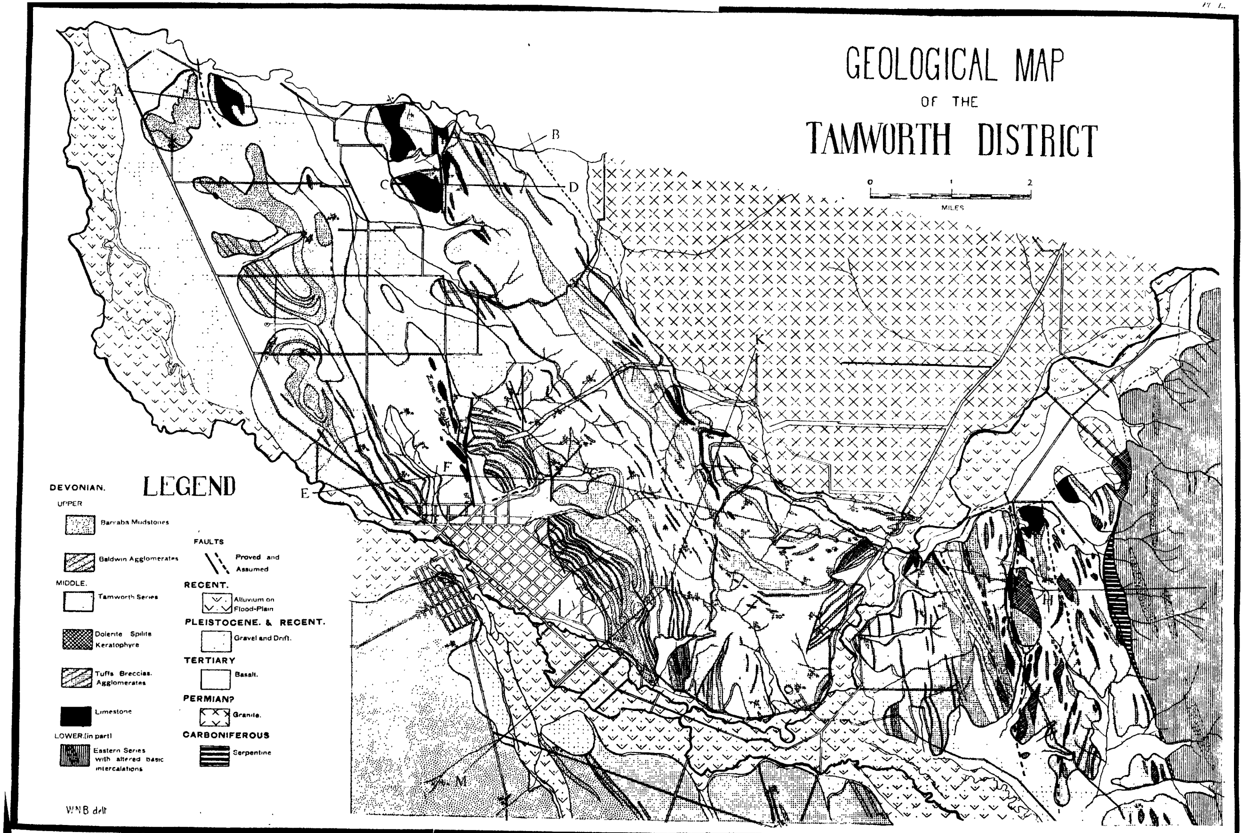
Page 143, line 12.—*for* "fig 3", *read* "fig.4".

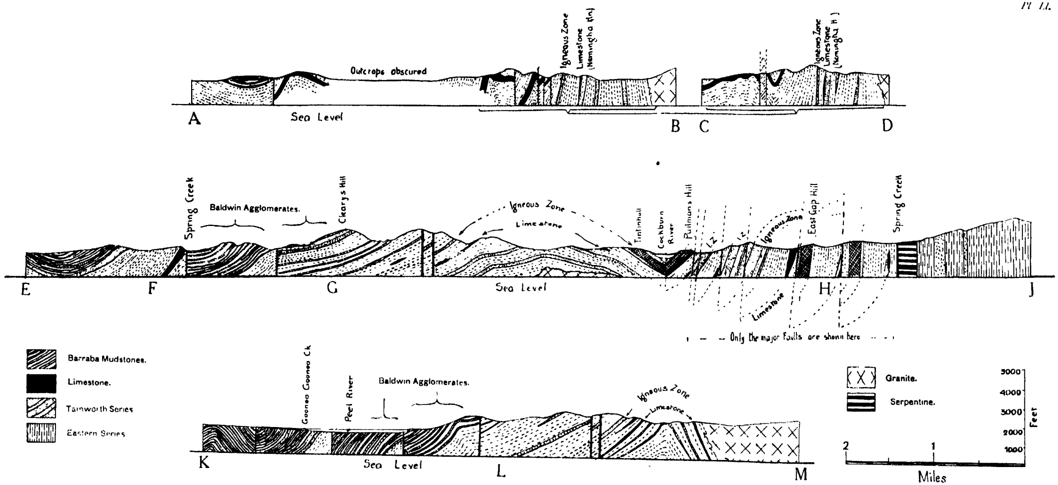
Page 160, lines 17-18.—*for* "From the nature of the case", *read* "For topographical reasons (see Map (1), Plate xxii.)"

Postscript (*added October 28th*, 1915).—M. Giraud's description of the peperites, (basaltic tuff-breccias) of the Auvergne, has come under the writer's notice while the above was in the press (Bull. des Services de la Carte Géologique de la France, No. 87, 1902, pp. 299-367). The author reviews an extensive literature, and concurs with M. Michel Levy in considering that the peperites are instrusive into the Oligocene marls in the Limagne. They form selvedges to basalt-dykes, developed where the dykes traverse weak structures, such as marls, but not where they invade strong structures, such as granite or limestone. Contact-effects are visible above as well as below the peperites. Where the overlying strata are sufficiently thin, the peperites broke through to the surface, and were deposited in water; such sedimentary peperites contain

organic remains, *Helix*, etc. M. Michel Levy thought the conversion of the basalt-magma into fragmental material, was perhaps due to the rapid escape of water from the magma, in regions where the containing walls of the dyke offered little resistance. It is often difficult to draw any line between the solid basalt and the marginal breccia, which has been thrust laterally into the weak structures. Sir A. Geikie remarks: "The material of the peperites has undoubtedly here and there filled up the volcanic vents, and has been injected in veins and dykes around their margins. But the main mass of the material was ejected from the vents, and falling, as volcanic dust and sand . . . became interleaved with the contemporaneous sediments" (Textbook of Geology, 4th ed., p. 1255, footnote). It seems reasonable to suppose that, if loose marls below solid limestones, permit a magma to break up into pyroclastic material, such an action will be even more favoured in loosely consolidated sediments without a compact covering layer. To this extent, the French peperites help us to understand the features of the Tamworth tuffs. One cannot, however, decide to what extent the pulverisation of the consolidating magma was brought about by the escape of magmatic water, or by the constant forward movement of the magma, or by the strains set up, as in a Prince Rupert drop, by the rapid chilling of the melt. The general absence of recognisable points of eruption makes it also impossible to estimate the distance to which the intrusive tuffs have been thrust laterally into the sediments. But though clearly intrusive tuffs have been found at many points, it is probable that the fossiliferous tuffs and breccias deposited in the normal fashion constitute the greater part of the pyroclastic rocks in the Great Serpentine Belt.


TOPOGRAPHICAL MAP
OF THE
TAMWORTH DISTRICT
Moore Creek
To Manilla
Margin of Flood-Plain
Househfield's Hill
Back Creek
To Bendemeer
To Brisbane
Kootingal (Moonbi)
COCKBURN RIVER
Margin of Flood-Plain
Yellow Gully
Spring Ck
Gap Ck
East Gap Hill
West Gap Hill
Oakey Ck
Nemingha Ck
To Nundle
PEEL RIVER
Seven Mile Ck
Tintinhull
Lev's Springs
Cleary's Gully
Long Gully
Spring Ck
Loder's Gully
Two Mile Ck
Nemingha
TAMWORTH
To Manilla
To Sydney
Goonoo Goonoo Creek
Margin of Flood-Plain
PEEL RIVER
SCALE
Miles 0 1 2 3
Contour-Interval 200 Ft.
Heights based on Aneroid-Observations
WNB delt


GEOLOGICAL MAP
OF THE
TAMWORTH DISTRICT
0 1 2
MILES
A
B
C
D
E
F
K
M
Zone of Faults
LEGEND
DEVONIAN.
UPPER
Barraba Mudstones
Baldwin Agglomerates
MIDDLE.
Tamworth Series
Dolerite Spilite Keratophyre
Tuffs Breccias. Agglomerates
Limestone
LOWER (in part)
Eastern Series with altered basic intercalations
FAULTS
Proved and Assumed
RECENT.
Alluvium on Flood-Plain
PLEISTOCENE. & RECENT.
Gravel and Drift.
TERTIARY
Basalt.
PERMIAN?
Granite.
CARBONIFEROUS
Serpentine
W.N.B. delt




GEOLOGICAL SECTIONS ACROSS THE TAMWORTH DISTRICT.

organic remains, *Helix*, etc. M. Michel Levy thought the conversion of the basalt-magma into fragmental material, was perhaps due to the rapid escape of water from the magma, in regions where the containing walls of the dyke offered little resistance. It is often difficult to draw any line between the solid basalt and the marginal breccia, which has been thrust laterally into the weak structures. Sir A. Geikie remarks: "The material of the peperites has undoubtedly here and there filled up the volcanic vents, and has been injected in veins and dykes around their margins. But the main mass of the material was ejected from the vents, and falling, as volcanic dust and sand . . . became interleaved with the contemporaneous sediments" (Textbook of Geology, 4th ed., p.1255, footnote). It seems reasonable to suppose that, if loose marls below solid limestones, permit a magma to break up into pyroclastic material, such an action will be even more favoured in loosely consolidated sediments without a compact covering layer. To this extent, the French peperites help us to understand the features of the Tamworth tuffs. One cannot, however, decide to what extent the pulverisation of the consolidating magma was brought about by the escape of magmatic water, or by the constant forward movement of the magma, or by the strains set up, as in a Prince Rupert drop, by the rapid chilling of the melt. The general absence of recognisable points of eruption makes it also impossible to estimate the distance to which the intrusive tuffs have been thrust laterally into the sediments. But though clearly intrusive tuffs have been found at many points, it is probable that the fossiliferous tuffs and breccias deposited in the normal fashion constitute the greater part of the pyroclastic rocks in the Great Serpentine Belt.

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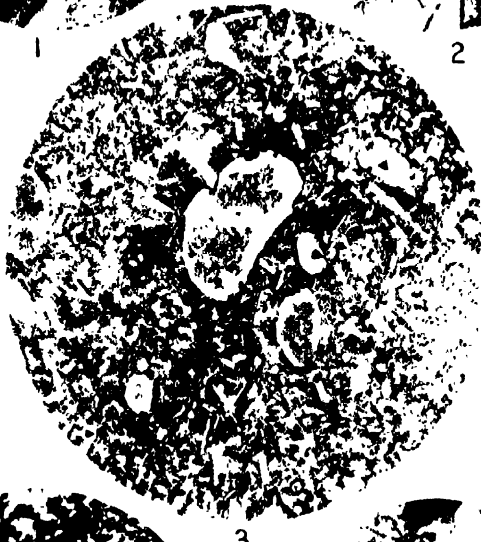

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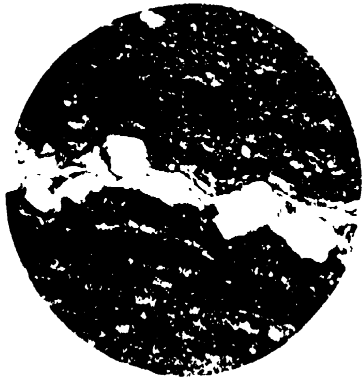
4

5

6



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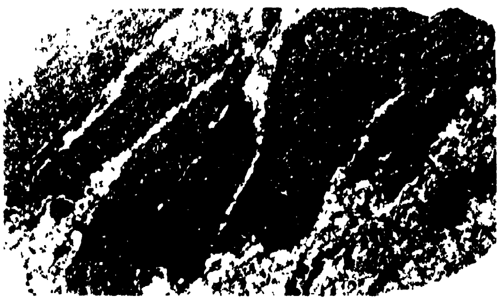

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9

10

# NOTES ON THE GEOLOGY OF THE CRADLE MOUNTAIN DISTRICT,

## With a Bibliography of the Pleistocene Glaciation of Tasmania.

By W. N. Benson, D.Sc., B.A., F.G.S.

Plates I.-IV.

(Communicated by W. F. D. Butler, M Sc , LL.B., B.A )

(Read 3rd April, 1916.)

Owing to the kind invitation of Mr Rodway and Professor Flynn, the writer had the good fortune to be a member of a party spending the last week of 1915 in Mr. Weindorfer's Accommodation Hut near Cradle Mountain in the north-west of the Tasmanian highlands Though there was little opportunity for detailed geological work, many interesting features were observed, which, at the request of the leaders of the party, are here recorded, and correlated with the scattered references to this region in the writings of the few geologists that have previously been in the neighbourhood A sketch map of the geological features, and a topographical sketch map are also given, based on a manuscript map by Franz Malscher, supplied by Mr. Weindorfer, and amended in accordance with surveys made by the present party. The following account must be considered rather tentative, since lack of time prevented complete verification.

Cradle Mountain may be reached most easily by the road from Sheffield through Wilmot and the Middlesex Plains, a distance of forty miles. The track crosses the Isis River and Pencil Pine Creek, and then follows the Dove River to the foot of the mountain. The formations traversed by this route, or adjacent thereto, are the Pre-cambrian schists, the Cambrian sandstones, quartzites and conglomerates, Silurian limestones, Devonian granite, and Tertiary basaltic rocks (which are of several types, varying from dolerite to tachylite), and alluvial deposits. (1).

The four main formations in the vicinity of Cradle Mountain and Barn Bluff are the Pre-cambrian schists and quartzites, the Permo-carboniferous conglomerates, sandstones and mudstones, the Cretaceous dolerite, and

(1) W, H. Twelvetrees. Bibliography No. 42.

the Pleistocene glacial deposits. A little recent alluvium is also present. The general disposition of the first three series is roughly indicated in Mr. Johnston's official Geological Map of Tasmania of 1884, the earliest chart to which the writer has had access. A more accurate representation is found in the map given by Jeffrey Smith, "based on information supplied by the Geological Survey of Tasmania." (2).

The Pre-cambrian rocks of the region have been briefly described by Messrs. Waller (3) and Ward. (4) The latter remarks that at Barn Bluff they strike a few degrees north of west. Between here and the Forth River the strike, according to Waller, is nearly east and west. In the immediate vicinity of Cradle Mountain the writer found the strike to be between E.N.E.-W.S.W. and N.N.E.-S.S.W., the former direction predominating to the north-east of the mountain; while to the north-west, along the Dove River, rocks have been observed striking west of north. Evidently there is a great bend in the Pre-cambrian fold-axes in this region. The rocks are intensely folded; numerous sharp anticlines and synclines are visible. The dips are nearly vertical, and easterly dips are usually steeper than those directed towards the west, while the latter are more common. These facts suggest that overfolding has occurred under the influence of a thrust directed from the west.

The rocks present are all of sedimentary origin. They include dark grey phyllite, coarsely crystalline mica-schist, micaceous quartz-schist, felspathic quartz-schist, and schistose quartzite, showing abundant evidence of recrystallisation, and, indeed, passing locally into vein-like masses of quartz. True veins of quartz traverse the other rocks, occurring lenticularly in the bedding-planes or running obliquely thereto. Four samples have been examined microscopically; the following are brief descriptions of the same, using the terminology adopted by Grubenmann (5):

> 1461. Puckered Phyllite (helicitic texture). This consists of a granoblastic ground mass of quartz-grains, with wavy bands of finely-divided carbonaceous matter, sericite, and bleached biotite, the whole more or less stained with limonite.

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(2) A Naturalist in Tasmania. London, 1909.

(3) See Bibliography No. 21.

(4) L. K. Ward. Contributions to the Geology of Tasmania. Systematic Geology. The Pre-cambrian. Proc. Roy. Soc. Tas. 1909.

(5) Die krystallinen Schiefer. Second edition, 1910.

1464. Mica-schist with a lenticular schistose texture consisting of granoblastic quartz, with large irregular porphyroblasts of orthoclase, generally blackened by inclusions of carbonaceous matter. These have resisted the shearing much better than the quartz, and are a frequent cause of the irregularity of the lenticular texture. A pale green mica is abundantly developed in the numerous shearing planes, and extends out from them. Sericite is also present, and a very little andalusite and rutile.

1465. Mica-schist with lenticular texture, consisting of long irregular lenticles of close-packed pale green weakly pleochroic mica, partially chloritised, separated by layers of granoblastic but more or less elongated quartz grains. Large porphyroblasts of felspar, generally orthoclase, but also albite, interrupt the continuity of the lenticles of mica and quartz. Inclusions in these often continue the planes of schistosity Small grains of magnetite are scattered throughout the rock, and a few grains of andalusite have been noted

1466 A much crushed schistose quartzite, exhibiting perfectly the klasto-porphyritic structure It consists of large quartz-grains with very undulatory extinction and shattered margins, a few irregular uncrushed grains of albite, and a ground mass of finely comminuted quartz, with a few shreds of sericite

All these rocks are characteristic of the uppermost zone of Grubenmann's classification of the crystalline schists. This bears out Mr. Ward's view concerning their nature.

The Permo-carboniferous rocks lie on a very uneven surface of the crystalline schists. The irregularity is particularly clear under Mount Brown, on the southern side of Rodway Gorge. The basal portion of the series consists of conglomerate containing pebbles derived chiefly from the Pre-cambrian series, but also from the Devonian granites and other formations. They pass up into pebbly sandstones and mudstones. A thickness of about seventy feet of conglomerate occurs beneath the north end of Cradle Mountain, but this increases considerably to the south and east. There is apparently not less than five hundred feet of the sediments beneath Mt. Brown, while

Mr. Montgomery records the presence of a thousand feet of sediment beneath Barn Bluff. The basal beds at the last locality comprise a hundred feet of conglomerate, followed by two feet of cannel coal, enclosed in black micaceous shale containing *Glossopteris* (*ovata?*) and *Noeggerathiopsis sp.* Above this lie nine hundred feet of marine mudstone, shale, sandstone and conglomerate similar to those occurring at Mt. Pelion, nine miles to the south-east, which contain such typical Permo-carboniferous fossils as *Fenestella*, *Spirifera*, *Productus*, *Aviculopecten* and *Stenopora*. (6) Mr. Waller has estimated the series at Mt. Pelion to be from a thousand to fifteen hundred feet thick. (7) Thus the Permo-carboniferous basin becomes deeper towards the south-east, and many of the outcrops show a slight tilt in that direction.

At the surface in contact with the overlying dolerite, the mudstones are more or less altered, silicified and indurated. Small veinlets of opal traverse the bands of black carbonaceous shale. The alteration does not extend more than about a foot from the dolerite. It is well exposed on the northern face of Barn Bluff.

The Cretaceous dolerite caps Mt. Brown, Barn Bluff, and Cradle Mountain. It has the same general characters as the Mesozoic dolerite in other parts of the island, and may be considered to be portions of sills once continuous with the dolerites of the Pelion Range. Waller affirmed this former continuity, but doubted the intrusive character of the dolerite. (8) An examination of the base of the dolerite on the northern face of Barn Bluff, however, shows that it transgresses to a small extent across the bedding planes of the mud stones; and in the case of Cradle Mountain the dolerite rests on sandstones in the southern end, but on the underlying basal conglomerate on the northern. No feeding dykes were observed, but attention might well be directed to the north-eastern foot of Cradle Mountain, where, as seen from a distance, the dolerite appears to pass down through the Permo-carboniferous rocks, to come into contact with the Pre-cambrian schist. (See Plate 3.) The dolerite on Barn Bluff is about 650ft. thick, that on Cradle Mt. 700ft., but that on Mt. Brown is perhaps not more than 300ft. Columnar structure is very pronounced in the two former masses; but in places the predominance of one direction of vertical jointing causes instead a platey structure.

(6) See Bibliography No. 13

(7) See Bibliography No. 21

(8) Op. cit. supra.

The petrological character of the dolerites is of interest. They are of medium grainsize, and consist predominantly of plagioclase and pyroxene. The plagioclase forms small, more or less, idiomorphic tabulæ, somewhat zoned, the central portion having the composition of bytownite. The pyroxenes are more varied, a rhombic and two types of monoclinic pyroxene are present. In a rock from the lower portion of the dolerite on Cradle Mt. (1458) there is a normal, more or less, ophitic augite (sometimes subidiomorphic), with the usual large optic axial angle. associated with, and frequently including prismatic crystals of enstatite. In a rock from the summit of the mountain, however, the monoclinic pyroxene, which is partly subophitic, partly subidiomorphic, has two distinct types, namely, those grains which have the normal optic axial angle (which are in the minority), and those which are approximately uniaxial, indicating that they contain a large excess of magnesian silicate, i.e., are magnesium-diopside, or the augite-enstatite of Wahl. This mineral has been previously recorded in the dolerite of Cataract Gorge by Osann [9], and is known to be fairly common in other occurrences of dolerite in Tasmania. [10] In both these rocks, there is a small amount of magnetite and of very finely crystalline intersertal granophyre, dotted with crystallites of magnetite The former of these rocks contains grey felspathic veins at first thought to be granophyre. They prove to have a highly ophitic to poikilitic texture. The pyroxenes are sometimes roughly prismatic, ophitic or broken up into isolated patches, which are in optical continuity over quite large areas. The pyroxene is quite fresh, usually uniaxial, but sometimes of the normal character. There are, in addition, small prisms of enstatite. The felspar is slightly zoned, has the general composition $Ab_1An_2$ and forms a few small phenocrysts. Between the tabulæ is a small amount of minutely crystalline granophyre. A few large grains of magnetite are also present

Two inches from the chilled margin of the dolerite of Barn Bluff the rock is very fine-grained, with an intersertal structure. It contains small phenocrystic laths of plagioclase and larger prisms of augite, more or less converted into chlorite and carbonates At the margin itself, the grainsize is extremely minute, and the texture appears to be subvariolitic. Both these rocks contain vesicles

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(9) Ueber einen Enstatitaugit-führenden Diabas von Tasmanien Centbl. für Min., 1907, pp. 705-11. Translation by W. H. Twelvetrees Ann. Rep. Dept. Mines, Tas., 1907.

(10) J. A. Thomson, Journ and Proc Roy. Soc. N.S.W., 1911, p 306

filled with quartz, carbonates, and hæmatite. There is a remarkable absence of magnetite and of glass.

The Pleistocene and Recent deposits will be best considered with the general physiography, which we now proceed to discuss.

The writer is indebted to Mr. Twelvetrees's report on the adjacent Middlesex district for an account of the general relation of the physiographic features to the regional topography of Tasmania. He states, "The entire area is an elevated plain or tableland, dissected by stupendous gorges, and diversified by residual mountain ranges." He indicates that the tableland is separated by faults near Mt. Roland and Bell Mt. from the lower plateau near Sheffield and Wilmot, and lies at an elevation of 2,200-2,600ft. in the neighbourhood of Middlesex. (11) It rises gradually to the south-west, and around Cradle Mt. it lies about 4,000ft. above sea level. The plateau has here cut across the uneven surface of contact of the Pre-cambrian and Permo-carboniferous rocks, so that the surface of the plateau consists of irregular areas of the two formations The more siliceous Pre-cambrian rocks rise in small residuals, but the three dolerite mountains form the greatest monadnocks The plateau is trenched by the great gorges of the Forth River and its tributaries, to the east of Cradle Mountain, and by the gorge of the Fury on the west. The effects of the Pleistocene glaciation are everywhere visible, and to these we will devote special attention.

Six periods may be recognised in the development of the present topography In the first, possibly early Tertiary period, the dolerite-sills were laid bare by erosion, and a roughly horizontal surface of erosion or peneplain was produced in the dolerite. An uplift followed of more than a thousand feet, and the present peneplain-surface was cut out of the older level, fragments of which remain as residuals, such as Cradle Mt. and Barn Bluff. A mature system of valleys was originated between these, and, in particular, the course of the Forth River was outlined The third period was one of oscillatory uplift, accompanied by gentle tilting. The numerous immense gorges of the Forth and Pieman River systems were produced by revival of the ancient matured valleys. Tributary gorges such as Hanson's, Rodway's, and the Fury cut themselves right back to the foot of the residual mountains, while others, such as Smith's Creek and the Dove River, and Pencil Pine Creek, were considerably deepened in their

(11) Bibliography No. 42

lower portions, but the gorges had not cut back to the heads of the streams. During this period of alternating uplift and aggradation, flows of basalt occurred on several occasions outside the special area here considered. The oldest basalts, with their intercalated gravels, cover Middlesex Plains, and were probably connected with those above Lorinna on the other side of the Forth Gorge (as shown by Mr. Twelvetrees). The upper portion of the gorge is a wide, open valley, in which there is a thick mass of gravel covered with basalt. Below this there are newer gravel terraces, and the present stream has cut down below these, thus giving a perfect example of a valley-in-valley topography. (See Bibliography 42, Plate IV.) According to Mr. Andrews's view, the gravels were probably deposited during periods of subsidence between the successive uplifts. ([12]).

The remaining periods are those of maximum glaciation, retreat of the glaciers, and finally the period of post-glacial erosion. Possibly further research will show that the period of maximum glaciation comprised two or more maxima with intervening periods of retreat, as has been determined for the glaciation on the mainland, ([13]) but there is not sufficient evidence to permit of this conclusion at present. The period must here be considered as a whole.

Glacial features have been noted in this region by Sprent (3), Montgomery (9, 13), Waller (21), Twelvetrees (31), and Noetling (38), but no detailed description has been given. At the time of maximum glaciation an ice-sheet extended over the whole region, the three main prominences being probably the only points emerging above the snow. The main directions of ice-flow were determined by the pre-glacial valleys that were roughly radial about Cradle Mt., but important overflow-glaciers were developed as the level of the ice rose, and adjacent streams became confluent. In describing the manner in which these influenced the topography, we commence at Barn Bluff. The ice moved radially from this peak. To the west it fell over the gorge of the Fury, and was there broken up and melted. It does not seem likely that any mass of ice moved down this valley, since it appears to be a typical water-worn valley with overlapping spurs. To the south-east the ice moved out on to the plateau, scooping out the broad and probably shallow

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(12) E. C. Andrews. Geographical Unity of Eastern Australia. Journ. and Proc. Roy. Soc. N.S.W., pp. 420-480, especially p. 455.

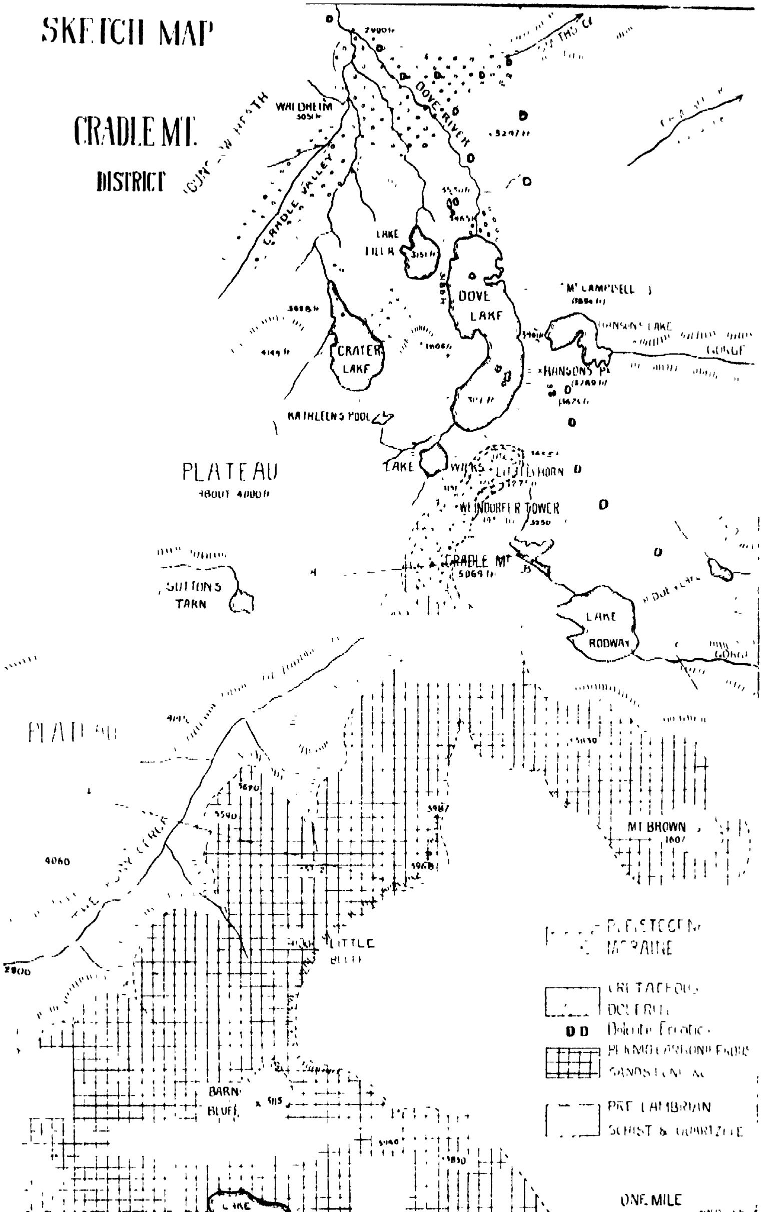
(13) David, Helms, and Pittman. Proc. Linn. Soc. N.S.W., 1901, pp. 26-74. David. Ibid., 1909, pp. 657-668.

basin of Lake Will, at the foot of the Bluff. North-east of the Bluff the ice-sheet moved across the plateau and fell into the gorge of the Forth River. Numerous small lakes were developed, such as Windermere and Agnew; their position probably depending on differential erosion, the mica-schists, and the soft Permo-carboniferous sediments being easily picked out. The ridge running to the south-east from the Bluff separated the northerly from the southerly flow, and is heavily cumbered with morainic material. Plucking of blocks of rock out of their original position must have gone on to a great extent, for one finds large blocks (up to 16 by 11 feet in area) of comparatively fragile coal measures, lying among the debris (Montgomery 13).

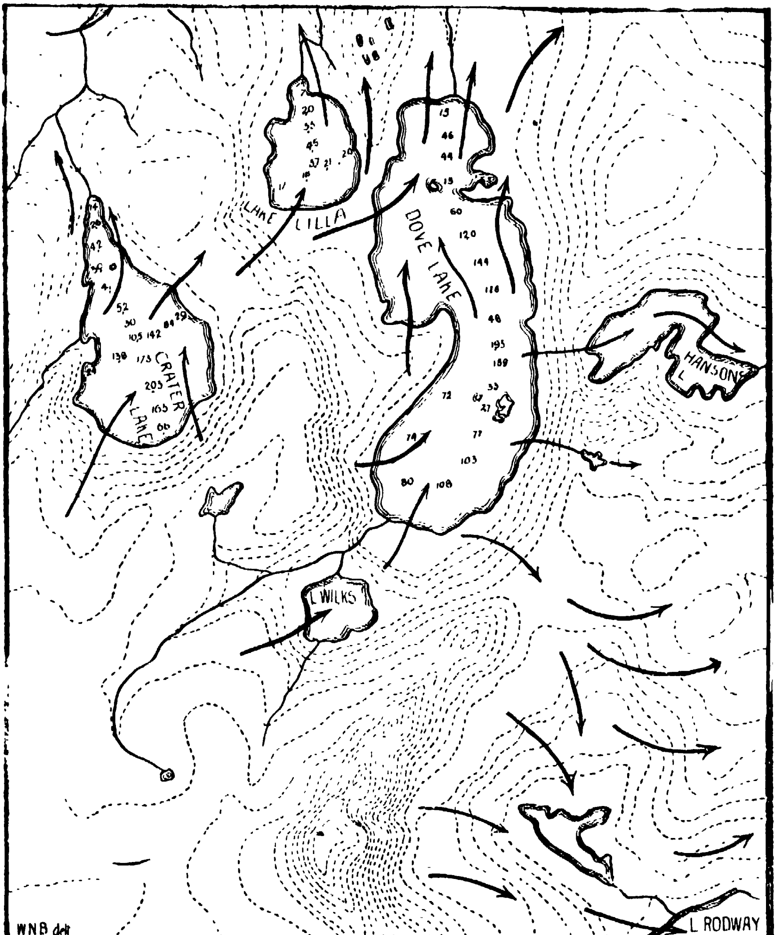
The eastern side of the ridge joining Barn Bluff and Cradle Mt. is broken into a great cirque with minor embayments, which surround the heads of tributaries of the Forth River. The ridge consists of horizontal sediments lying on the ancient rocks, which form the floor of the broad and relatively shallow cirque. Its eastern side has been sapped back into a continuous cliff. The floor is heavily glaciated and littered with morainic material. To the east the glacier from this cirque joined the ice-sheet on the plateau and fell over into the Forth River Gorge. West of the connecting ridge there is little sign of glaciation, the surface sloping regularly down into the Fury Gorge. Possibly the dominant west wind prevented the accumulation of much snow on this slope. ([14])

East of Cradle Mt. is the grandest example of a cirque in the district. On its floor is the lake for which the name Lake Rodway has been suggested. It lies in a broad and deep trough, around the head of which rises the crescentic ridge of Cradle Mountain. It is probable that the name of the mountain was derived from the resemblance this trough and rim-ridge bear to a miner's cradle. The crescentic form of the ridge is due to the cirque eating deeply into the eastern side of the original monadnock, while the western side has been scarcely affected; a further instance of asymmetry. The cirque is not simple, but is broken into four steps, by transverse bars of quartzite. (See Plate 3.) The "treads" of the two upper steps are narrow, the third is broader, and bears a small shallow lake, the outlet of which falls over a strongly glaciated bar into the main basin of Lake Rodway, the depth of which has not been ascertained. A

(14) Compare G. K. Gilbert, Systematic Asymetry in the High Sierras of California. Journal of Geol., 1904, pp. 570-586.



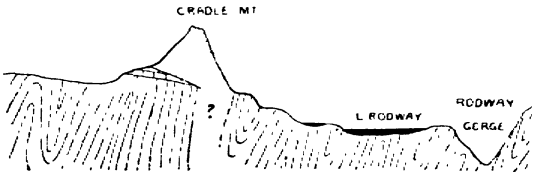

GEOLOGICAL SKETCH MAP OF CRADLE MT. DISTRICT



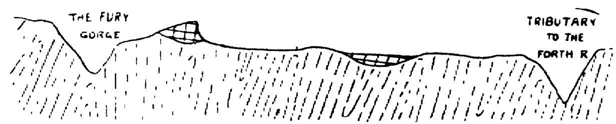

TOPOGRAPHIC SKETCH MAP OF CRADLE MT AND LAKES.

The arrows indicate direction of Ice movement during Glacial Period Scale, 1 inch 640 yards.

Contour Interval about 100 feet Soundings in feet. (Figures approximate only)



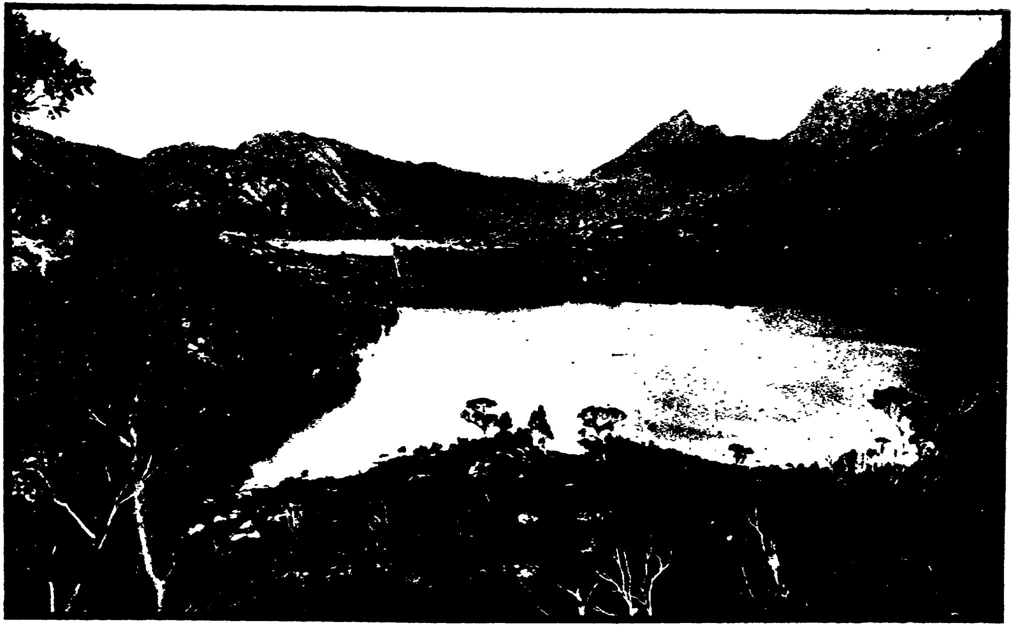

SECTION ALONG THE LINE ABC.




SECTION ALONG THE LINE EF, EXTENDED EASTWARD

ICA CTIONS ACROSS CRAD MT DISTRIC .)

VIEW CRADL ROM THE EAS BARN UFF TH BACKGROUND ON




AND DOVE LAKE, NORTH END CRAD MT. ON RIGHT
MT. BROWN IN BACKGROUND (C

broad glaciated bar follows, beyond which the stream falls directly into Rodway Gorge, which is a water-cut canyon. The boundary between the glaciated and water-cut surfaces is sharply marked. To the south, the main basin was extended by a cirque, cutting back into the soft Permo-carboniferous rocks of the ridge joining Cradle Mt. and Mt. Brown. This cirque, however, does not contain a lake, and is separated from Lake Rodway by a long moraine.

In the period of maximum glaciation, this great trough must have been filled to overflowing with ice, which was more than a thousand feet deep. Overflow-glaciers made their way over the northern rim of the trough, bearing boulders of dolerite, now scattered erratically. Once over the ridge, they broke up, fell down into a small gorge, were more or less recemented there, and, joined by the overflow-glacier from near the outlet of Rodway Lake, they scooped out a little rock basin before finally falling into the canyon proper. This little basin may be aptly named the Hidden Lake. The passage of the overflow-glaciers has cut the northern ridge, bounding the great trough, into a succession of cross-ridges of quartzite and hollows cut in mica-schist.

North of Cradle Mt. lies Dove Lake, a deep rock basin formed by the enlargement by glacial erosion of the upper part of the Dove River. The ice from the plateau and the north-western face of Cradle Mt., a total area of about 1,000 acres, collected in the head of the stream, passed down a steep fall on to a "tread" 400ft. below the plateau, where Lake Wilks was cut out. A second tread was formed near the lake-level, after a further fall of about 300ft. The further effect of the ice is shown by the soundings. (These were measured from a raft in a strong breeze, and must be considered as rough approximations only, both in depth and position.) The upper end of the lake is a basin at least 108ft. deep, separated from a basin almost 200ft. deep by a quartzite ridge (at one point only 72ft. deep, but rising into islands). The shallow point (48ft.) beyond the second basin probably marks a ridge connecting the quartzites of the great promontory with those of Mt. Campbell, on the opposite side of the lake. Beyond it is another deep (144ft.), separated by a quartzite ridge and islet, from the westernmost basin (46ft.), in which the Dove River ice was joined by the overflow from Crater Lake. The outlet stream passes over a drift-covered plain, probably concealing a rock-bar. Further soundings of this lake are very desirable.

In addition to this moulding of the floor of Dove Lake, the smooth curve of the eastern wall was rounded out by the middle portion of the glacial stream, while above, overflows made their way to the north-east. A large flow went past the northern end of Cradle Mt. to join the ice in the Rodway Valley, a second passed over the ridge south of Hanson's Lake, scooping out the little group of tarns there. A third passed over the gap into Hanson's Valley, converting the head of the valley into a lake basin. The contrast between this beautiful cirque-lake and the rugged water-cut gorge below it is very striking. These three overflow-glaciers were 400ft. above the present level of Dove Lake. At the northern end of Dove Lake overflows of ice passed across the watershed and dolerite boulders may be found high up on the slopes which lead down into Smith's Creek.

Lake Lilla owes its origin to the flow of ice that came down from the Crater Lake. It is a shallow pan, the greatest depth found being 45ft. The ice escaped from here over a rock bar into Dove Lake. An interesting feature is the almost complete removal of the old divide between Lake Lilla and Dove Lake, the ridge between the two lakes rising only thirty feet above the level of Dove Lake. (See Plate 4.) The outlets of the two lakes are separated by a beautiful roche moutonnée hill. The various strata cross this diagonally, and the surface of the hill, otherwise quite smooth, is pitted with jagged hollows, containing lakelets, and marking spots where vast masses of rocks have been plucked out by the moving glacier. No better examples of this process could be desired than are to be seen here.

Crater Lake is another most interesting feature, clearly exhibiting differential glacial erosion. Its southern end is a great cirque-wall rising more than five hundred feet above the lake, and cut into a mass of rather soft felspathic schist between quartzite bands. The lake is here 203 feet deep. The centre of the lake is crossed by a bar of quartzite only 30ft. below the surface. This bar continues to the north-east of the lake, forms the small knoll near the outlet, and extends down to cross the outlet of Lake Lilla. The side of the knoll is polished and grooved by the ice-stream from Crater Lake, which passed down into Lake Lilla. The gap by which this stream escaped from the Crater Lake basin has been filled by a ridge of morainic material which now rises about a hundred feet above the lake. The northern portion of Crater Lake contains two basins, as shown

by the soundings, and the outlet passes over a rock-bar, and enters Cradle Valley as a stream hanging nearly 600ft. above the base of the main valley.

Another well-marked cirque appears on the northern side of Cradle Valley, about a mile above the accommodation house. It is cut down out of Hounslow Heath to a depth of about 700ft., and enters the main valley almost at grade. There is a little morainic matter in the floor of this cirque, but no lake. No well-marked cirque occurs at the head of the Cradle Valley, which has, nevertheless, been greatly modified by glacial action. It is a broad, deep, steep-sided valley. The glacier which filled it received tributaries from the Crater, Lilla and Dove valleys, and escaped in part by the present Dove Valley, but also a large overflow passed over the col and down Smith's Creek. Dolerite-erratics have been traced down the Dove River about half a mile below Cradle Valley, and about a mile down Smith's Creek, and probably extend to the commencement of Smith's Gorge a mile or two further down.

No detailed study has been made of these terminal regions, in which the complex record of retreat and advance may ultimately be deciphered. There seem to have been small gorges cut in the older glaciated valleys, and some sign that these have been subsequently occupied by ice, but it is not clear whether this is the work of inter-glacial river action or merely of subglacial streams The well-timbered character of these valleys prevents the observer from obtaining a general view of the whole.

The last stages of the period of glacial retreat were responsible for the moraines in Cradle Valley. Typically hummocky moraine fills the lower part of the valley and extends across into Smith's Creek. A lateral moraine extends along the southern side of the Cradle Valley, rising 250ft. above the floor. An arcuate terminal moraine closes the outlet of Lilla Creek, and a thin ridge of moraine extends down towards the outlet of Crater Lake, possibly a remnant of a small terminal moraine. It is interesting as showing the mark of an overflow-channel fifty feet above the present outlet. Small masses of morainic material occur in most of the cirques mentioned.

The final period of post-glacial erosion has had very small results. Some morainic material has been removed, and small outlet valleys notched in the terminal moraine, and patches of alluvium have been formed.

Summarising, we may say, that though the glaciers here were large enough to overflow their valleys, there is

no evidence that they extended far to the north, but occupied only the comparatively mature upper portions of a rejuvenated river system, and did not extend beyond the heads of the canyons which then reached to within a few miles of their source. In the gorge of the Fury, which had been cut back almost to its source, no sign of glaciation was observed.

The writer is indebted to all the members of the party for assistance in various ways, especially in raft-building and sounding. Mr. Butler's and Mr. Maxwell's photographs have been most useful in the preparation of the paper. Mr. Butler has provided the amended copy of Malscher's map, which is the basis for the geological map herewith, and Mr. Twelvetrees has kindly discussed with the writer some of the questions here raised and added items to the Bibliography. To his father, Mr. W. Benson, the writer is indebted for Plate 3 herewith, based on photographs, sketches and descriptions. Plate 4 is from a photograph by Mr. Spurling, of Launceston.

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The GEOLOGY of the COOMA DISTRICT, N.S.W.

# THE GEOLOGY OF THE COOMA DISTRICT, N.S.W.

## PART I.

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[*Read before the Royal Society of N. S. Wales, July 1, 1914.*]

I. Introductory.

II. Stratigraphical and Descriptive.

Summary,

(*a*) The Metamorphic Series:—Schists and phyllites. Igneous gneisses—mottled, Cooma, blue, white and pink gneisses. Amphibolite. Pegmatites and quartz veins.

(*b*) Ordovician.

(*c*) Silurian.

(*d*) Post-Silurian but Pre-Tertiary:—Quartz-porphyries. Berridale granite. Myalla Road Syenite.

Geological age of the igneous intrusions.

(*e*) Tertiary and Recent:—Olivine Basalt. Diatomaceous earth. Travertine. River Gravels. Aeolian deposits.

III. Economic Geology:—Bushy Hill mines. Tripolite. Limestone. Barytes.

IV. Age of the Metamorphic Series.

V. Geological History up to Tertiary times.

VI. Physiography:—Present topography. Süssmilch's interpretation. Details of development of the river system. Age of the basalts. Origin of the lakes.

## I. Introductory.

Comparatively little has been written, and no detailed work has hitherto been done, so far as I am aware, in connection with the geology of the extremely interesting region round Cooma.

Rev. W. B. Clarke, in his "Southern Goldfields" (Chap. VII, and elsewhere) makes reference to the schists and gneisses, the olivine basalt, the chiastolite slates of Geygedzerick Hill, and the Berridale granite.

Professor David[1] makes passing mention of the metamorphic rocks, pointing out their lithological similarity to those of Mitta Mitta in Victoria, and to the Pre-Cambrian series along the eastern slopes of the Mount Lofty and Flinders Ranges in South Australia. He suggests that on these grounds the Cooma metamorphic series may be provisionally referred to the Pre-Cambrian.

The physiography of the region has been dealt with in papers by Süssmilch[2] and Griffith Taylor.[3] Other references will be given in the text.

The present paper is the outcome of a visit paid to Cooma in February 1912, at the suggestion of Professor Woolnough, for the primary purpose of examining the pegmatite veins occurring in the gneiss. My attention was attracted by the extent and variety of the metamorphic rocks in the neighbourhood, and a few excursions into the surrounding country suggested in addition some stratigraphical problems of interest.

The town of Cooma is on a branch of the Great Southern Railway Line, 266 miles from Sydney, and 130 miles south

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[1] Proc. Linn. Soc. N.S.W., Vol. xxxiii, 1908, p. 658.

[2] Notes on the Physiography of the Southern Tableland of N.S.W. This Journal, Vol. xliii, 1909, p. 331.

[3] The Physiography of the Proposed Federal Territory at Canberra. Commonwealth Bureau of Meteorology, Bulletin No. 6, Dec. 1910.

from the junction at Goulburn. It is 60 miles from Mount Kosciusko and is at a height of 2,662 feet above sea-level.

### II. Stratigraphical and Descriptive.

SUMMARY.—The country dealt with in this paper comprises a roughly elliptical area extending from Cooma about 9 miles to the north, 6 miles to the east, and to the south and west 11 miles each: the greater part of this area has been studied in considerable detail. The rocks outcropping include, in addition to a metamorphic series whose age is uncertain, representatives of Ordovician, Silurian and (?) later Palæozoic, as well as of Tertiary and Recent times.

The metamorphic complex consists mainly of mica-schists and quartz-schists in great variety, phyllites and quartzites. These are intruded by a gneissic series. Three varieties of gneiss are recognised, differing in texture and general appearance, and quite distinct from each other. These will be known as the mottled gneiss, the Cooma gneiss, and the blue gneiss respectively. A pink and a white gneiss are probably genetically connected with the blue gneiss. Among the gneisses and schists is found an amphibolite intrusion of limited occurrence, with associated dykes and apophyses of fine-grained pyroxene-amphibole granulite and schist. A number of pegmatite dykes also intersect the metamorphic complex.

The Ordovician rocks consist of slates, gritty slates and quartzites, and one small patch of limestone, unfossiliferous.

In the Silurian are comprised a considerable belt of limestone, slates, gritty sandstones, and quartzite; these lie to the east of the Ordovician rocks. On some horizons there is an abundant fossil fauna. Here too may possibly be included some very highly shattered quartz-porphyries which occur interbedded with the slates.

For reasons which will be mentioned later, a number of igneous intrusions are referred to the Devonian or Carboni-

ferous. These are the Berridale granite, the Myalla Road syenite, with accompanying dykes of bostonite, and lastly an extensive series of quartz-porphyry intrusions.

Tertiary and recent rocks are represented by basalts which are extensively developed over the area, by deposits of diatomaceous earth, of chemically-formed limestone and of alluvial. Late Palæozoic and Mesozoic formations are entirely absent. The strike of the sedimentary and metamorphic series is approximately meridional, the mean of about fifty compass readings being 347°.

(a) THE METAMORPHIC SERIES.—The rocks constituting this series occupy a considerable area on all sides of Cooma excepting the east, as may be seen from the map: to the south-west of Cooma they disappear under basalt, so that their southerly extension cannot be accurately determined. Schists, occurring as inliers amid the basalt, have been found 6½ miles due south of Cooma, and it is quite possible that metamorphic rocks extend much farther south. On the north the series has not been traced farther than Pearman's Hill, 9 miles north of Cooma along the Sydney Road: there is every reason to believe, however, that they extend a great many miles beyond this.

*The Schists.*—In the centre parts of the complex the schists are well crystallized, but on the east and west they pass gradually into phyllites: this is most noticeable on the west, where there is, beginning from the western side of Dairyman's Plain, a gradual transition into the Slack's Creek phyllites: on the eastern side the phyllite belt is not nearly so broad, and it is interrupted in some places by intrusions of gneiss, and in other places concealed by basalt flows. It is to be noted that the schists have a much wider extent to the west than to the east of a meridional line through the main outcrops of the Cooma and the blue gneisses. The sedimentary origin of these schists is proved

by the presence of interbedded quartzites in the form both of lenticular patches a few yards long and a few inches wide, and of more continuous layers. The prevailing quartzose nature of the schists too would tend to indicate their derivation from arenaceous sediments. There is a notable proportion of what may be termed quartz-schist, containing predominant quartz, with a subordinate amount of mica: ordinary mica-schist, too, is plentiful, and a mica-schist with porphyroblasts of (?) cyanite has been found in a few places in close contact with the blue gneiss. A very well-defined variation of the schist is really a kind of very fine-grained gneiss, according to Van Hise's definition of the term.[1] In hand-specimen a fracture perpendicular to the schistosity shows alternate bands of light and dark minerals on a small scale. The dark micaceous layers are about ·2 mm. thick, the more acid layers ranging between 1·5 and 2·5 mm. approximately. These rocks seem to be similar in origin to the other schists, with which they are intimately associated, and from which they cannot be differentiated. In many places the schists are interleaved with Cooma gneiss which has been subjected to mechanical deformation: the minerals have been broken up and the grainsize considerably reduced; in such cases it is often impossible to differentiate between a relatively coarse-grained schist and the mechanically altered gneiss.

The planes of schistosity often show much bending and puckering; this is rendered very noticeable when, as frequently happens, little pegmatite veins have been injected along these planes. The numerous pegmatite and quartz veins which occur throughout the schist generally follow the planes of foliation, and quite commonly there have been regular *lit par lit* injections of pegmatite.

[1] A Treatise on Metamorphism, p. 782.

*Slack's Creek phyllites.*—Along the western side of Dairyman's Plain, as has been mentioned, the appearance of the schists changes; quartz no longer appears megascopically, the chief visible constituent being mica, and the rocks grade into shimmering micaceous phyllites. These may be named the Slack's Creek phyllites,[1] from their conspicuous development there. A traverse westward from Kiaora homestead exhibited well the variations of these rocks. Succeeding the crystalline schists, very shiny mica-phyllites predominate. These are finely corrugated and highly cleavable. Closely associated are rocks of generally similar character, but more coarsely corrugated, and roughened by knots of (?) incipient andalusite. These knotted phyllites are very frequent in bands of a few inches to a foot thick: the boundaries between them and the bands of plain and finely corrugated phyllite are very sharp, and two varieties can readily be obtained in the same hand specimen.

Interbedded with the phyllites (for the planes of schistosity have also been bedding-planes) are bands of a hard dense dark blue quartzite or quartzitic schist, often a couple of feet or more in width. These quartzites also occur as lenticular bands about 3 or 4 feet long and 4 or 5 inches thick.

The prevailing dip of the phyllites is easterly and varies considerably in amount, from a very high angle down to about 30°.

Just about where the Dry Plain road crosses Slack's Creek there can be seen a black micaceous slate interbedded with the phyllites. Further up the creek, about

[1] The term *phyllite* has been objected to in view of the plainly autogenic character of the rock, but the name has been considered necessary on account of the markedly micaceous character of the rock as compared with the schists.

$1\frac{1}{2}$ to 2 miles north of where it is crossed by the Adaminaby road, the micaceous slates predominate, having interbedded with them occasional bands of smooth and knotted phyllite, as well as quartzite and a whitish-grey gritty variety of slate.

The Slack's Creek phyllites, as well as the schists, are conspicuously traversed by vertical joints running at a bearing of 80°, or nearly perpendicular to the strike. This system of jointing is noticeable along Spring Creek, at the Wallaby Rocks, and in other places where the schists outcrop. The phyllites are seamed with quartz veins and reefs. In general these bear no fixed relation to the strike of the country, but some have evidently been injected along the planes of schistosity. In some of the veins the quartz is strongly grooved and scored.

To the east of the metamorphic complex the transition from schist to phyllite cannot be traced so clearly as on the western side, partly on account of the capping of Tertiary basalt concealing the outcrops, and partly on account of the pink and white gneisses at Bunyan being intruded just about where the transition band should be. The belt of phyllites is only about one-third as broad as the western belt. It can be seen at intervals along the Sydney Road between Cooma and Bunyan; in only a few cases could slight knotting be observed.

*Igneous gneisses.*—Under this head are treated those three occurrences of gneissic rocks whose igneous origin has been proved beyond doubt, mainly by the presence of inclusions of the sedimentary schists and by definite evidence of intrusion.

On the Murrumbidgee, between Mittagang Bridge and Wallaby Rocks, in the hilly country east of the Bridge, and along the Murrumbucca Road, representatives of all

three varieties of gneiss are seen to intrude the schists, fragments of which they frequently include.

The limits of these three formations, and particularly of the Cooma gneiss and the mottled gneiss, cannot be definitely laid down, owing to obscuration of their textural peculiarities by metamorphic and other influences, and also to the fact that a great deal of the gneiss has been intruded as tongues along the planes of schistosity of the invaded formations. The mapped-in occurrences, therefore, must not be taken to represent the total extent of these rocks.

*The mottled gneiss.*—The mottled gneiss is the oldest of the three: it is a very fine-grained rock, with a characteristic mottled appearance due to the alternation of patches of biotite in wavy bands with patches of the light-coloured constituents. This mottled gneiss has a fairly wide distribution throughout the metamorphic area, in relatively small patches as a rule. Mount Gladstone (Cooma Hill), about three miles to the S.W. of Cooma, is composed principally of this rock, which is also found intruding the schists in various places, principally to the west of the town. So much alteration of the schist has taken place, through metamorphism due to intrusion and the injection of countless little pegmatite veins, and so much change in the mottled gneiss from similar causes, that it is at times impossible to separate them. No doubt a certain amount of contamination of the igneous material has taken place during the process of injection: indeed this is proved by the fact that microscopically sillimanite is seen to be a constant constituent of the mottled gneiss.

The appearance of the gneiss in hand specimen would never suggest its igneous origin, its fine grain and mottled schistose appearance being characteristic rather of an altered sedimentary rock. Indeed for a good while I was inclined to class it as such, until the discovery of schistose

inclusions, and of the occurrence of the rock in tongues through the schist, indicated its intrusive character beyond a doubt.

*The Cooma gneiss.*—The Cooma gneiss comes second in point of age. The main mass of it, which outcrops in and around Cooma, is about 5 miles long, the greatest breadth being a little over 2½ miles, but this by no means represents the entire outcrop, for isolated patches occur about 5 miles south of Cooma, and nearly as far west as Kiaora homestead, in addition to several small outcrops north of the town. Besides those occurrences which are definitely recognizable as Cooma gneiss there are numerous outcrops of crystalline rock which have all the appearance of Cooma gneiss which has undergone extreme crushing, producing a reduction in the grainsize and a schistose foliation. These probably represent tongues or upward injections of the original rock into the schists, which in consequence of their narrowness have suffered more from mechanical deformation than other intrusions of greater breadth. Such outcrops are to be found at many places among the schists to the north and west of Cooma. Occasional remains of large crystals of felspar or quartz, as well as lenticular inclusions of schist, point to the shattering of an original massive igneous rock. It seems probable, therefore, that the underground extent of the Cooma gneiss is much greater than might be determined from the main outcrop; in particular a considerable extension to the north and west of Cooma is indicated.

The original granite mass from which the gneiss is derived must have sent numerous apophyses into the surrounding rocks, and this is only to be expected, seeing that the invaded formations were probably already cleaved, and therefore possessed of planes of weakness, at the time of intrusion. These gneissic dyke-like intrusions are fairly

numerous, and a notable feature of their occurrence is that apart from the schistosity due to pressure their texture differs not from that of the main mass of the gneiss; in other words the original apophyses would appear to have been granitic, and not in the nature of quartz-porphyry, as might reasonably have been expected. This may be explained by supposing that the apophyses are really but short offshoots from the parent mass, or slight upward projections from the roof of the magma-chamber, so slight that the conditions of their crystallization did not differ essentially from those of the main mass. (See fig. 1.)

Inclusions of the intruded schists are fairly common in the Cooma gneiss in certain places. Beyond Mittagang Bridge on the Murrum-

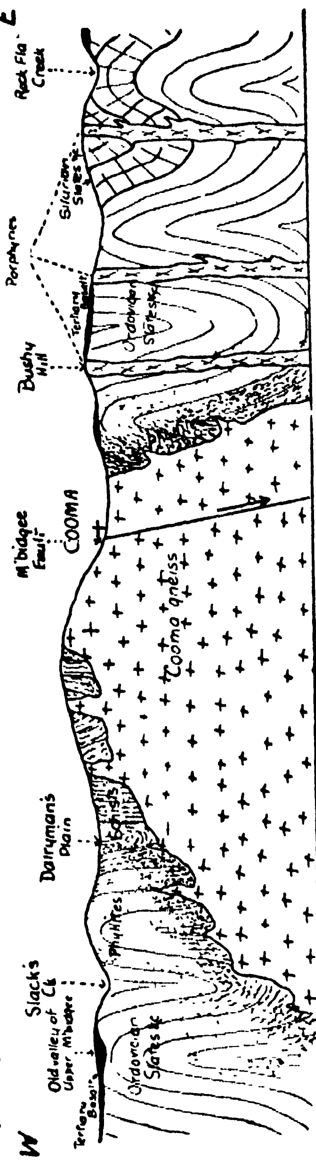


Fig. 1 —*E. W.* *Sketch section through Cooma, showing suggested relations of gneiss, schist, phyllite and slate, and of the Ordovician and Silurian, etc.*

bucca Road these are found of lenticular shape about three feet long, and with a maximum breadth of about four inches. They occasionally consist of a hard outer shell of an inch or one and a half inches thick, with a core of softer rotten schist. This may be a kind of case-hardening, due to the heat etc. of the eruptive rock. Partial digestion of the inclusions seems to have occurred, or their recrystallization, as exhibited in the cuttings just outside Cooma on the Berridale road.

In general appearance the Cooma gneiss is very variable. Typically it has quite a granitic fabric and massive structure, but at times it assumes a schistose appearance and develops a rude cleavage, particularly near its boundaries. Again, a typical gneissic structure may be exhibited, bands of light and dark minerals alternating, due in some cases to *lit par lit* injections of pegmatite, but often, I believe, to recrystallization at the time of metamorphism. Here and there are to be found dykes or bands of a more acid gneiss, consisting of quartz, felspar, and white mica, of the same general texture as the ordinary gneiss, but differing in the absence of black mica.

The normal gneiss itself consists, megascopically viewed, of quartz, felspar and biotite in varying proportions, generally with a subordinate amount of white mica. Locally the acidity of the rock may be increased, while again, especially along the borders of some large pegmatite vein, the biotite content increases very largely, giving the rock a very basic appearance. Preliminary microscopic examination shows the constant occurrence of topaz, and of little zircons with pleochroic haloes in the biotite.

The grain of the gneiss is as a rule very even, but felspars up to $1\frac{1}{4}$ inches long and quartz grains up to 4 inches long occur, giving the rock in places a porphyritic appearance. These are evidently fragments which have resisted crush-

ing, and would indicate that the original granite was either very coarse grained or else porphyritic. That they are not products of recrystallization their sparing distribution would show.

*The blue gneiss.*—The extent of this, particularly to the north, has not been fully traced. The investigated outcrop occupies a fairly large area some distance to the west of the Sydney road between Bunyan and Pearman's Hill, and is well developed at the point where the Murrumbidgee, in emerging from its V-shaped gorge in the Berridale table-land, executes a sharp S-shaped bend. Like the Cooma gneiss, the blue gneiss sends out numerous tongues into the surrounding rocks, and inclusions are frequent, also what look like basic segregations.

For the most part the rock shows well-marked foliated gneissic structure, but as one goes westward across the outcrop between Governor's Hill and the Murrumbidgee, one notices that about ¼ mile from the edge of the intrusion the rock loses its gneissic appearance and becomes granitic, resembling, in fact, a normal biotite granite. Here, too, it weathers into the great rounded tors characteristic of massive granite. At the southern end of the main intrusion there is a porphyritic and relatively acid facies, with pink, simply-twinned orthoclase phenocrysts measuring up to ½ inch by ¼ inch. As has been mentioned, numerous dykes of blue gneiss are found, usually with the strike of the schists. A long dyke-intrusion can be traced along the Mittagang Road from the Cooma Creek bridge nearly as far as the waterworks distributing reservoir about a mile out of Cooma; further on the same dyke appears in a rail-way cutting, crosses the Sydney road, and eventually disappears under the basalt behind Cooma Railway Station. A probable continuation of this dyke northward would make its total length somewhere about 6 miles. The width

of the outcrop varies; in some places it is upwards of 100 yards, thinning considerably towards the southern end. The gneissic structure is very pronounced, and the basicity of the rock increases towards the south, megascopic free quartz disappearing and the layers of biotite giving the rock the characteristic bluish-black appearance from which the whole gneiss has been named.

*The white and pink gneisses.*—Along the Sydney Road there is a long band of acidic gneisses which has been traced from a point $1\frac{1}{2}$ miles north of Tillabudgery Trig. Station as far as Pearman's Hill, a total distance of over $5\frac{1}{2}$ miles, and which may extend farther north still. At Bunyan the outcrop is not less than 400 yards in width, and it forms a strong feature on the west of the Sydney road for some distance past the Cooma Creek bridge. Two varieties of gneiss are recognised. The white gneiss has in many places strongly marked gneissic foliation, the folia consisting of quartz and felspar alternately, with subordinate development of white mica in small flakes. Apparently of somewhat later origin, since it intrudes the white gneiss, is a pink rock strongly jointed, very compact and seen under the microscope to consist mainly of quartz, with very subordinate felspar, the whole stained with hæmatite, and possessing marked schistosity.

The affinities of these two gneisses it has been found impossible to determine with complete satisfaction. Not far past Cooma Creek bridge the white and blue gneisses were found in close association, and what looked like an intermediate type of gneiss, very similar to the blue gneiss, but with very subordinate mica, was also seen. On the whole it seems as if the white and the pink gneisses were genetically related to the blue gneiss as later acid differentiates from the same magma. A pink rock which intrudes the blue gneiss at Pearman's Hill may be a phase of the pink

gneiss. It is however devoid of gneissic banding, and has more of the appearance of a felspathic porphyry.

*Amphibolite.*—In the town of Cooma, 200 yards or so south of the R. C. Church, is an outcrop of amphibolite intrusive into the Cooma gneiss. The main outcrop is of rudely circular form, and about 50 yards in diameter. The rock consists largely of coarse amphibole crystals up to $\frac{3}{8}$ of an inch long, medium and fine-grained modifications occurring in subordinate association. The first two kinds are massive, but the fine-grained rock is in places notably schistose, with bands of fine pegmatite running parallel to the schistosity. The mutual relations of the three varieties are obscure, the grainsize changing abruptly without any apparent reason.

Interstitial white material in the coarse and medium-grained varieties probably represents felspar. Apophyses from the main mass are thrown out to both north and south; medium-grained amphibolite is found in the street between the R. C. Church and Convent, and a narrow dyke can be traced for upwards of half a mile to the south. Pegmatite veins seam the main outcrop in all directions, and the southward dyke is generally in close proximity to a narrow vein of pegmatite.

Small isolated patches of amphibolite, usually not more than a yard or two in diameter, are found. One is on the north side of the Berridale road at the first rise out of Cooma, having associated with it ill-defined dykes of fine-grained amphibole schist; another occurrence of coarse-grained rock is at Pine Valley, a little north of the Berridale road, and a third has been noticed to the west of the Mittagang road, near the S.W. corner of Portion 108. These last two occurrences, like that in the town of Cooma, are closely associated with pegmatite veins: the probable significance of this will be discussed later.

This amphibolite must be taken to represent an original dioritic or gabbroic rock intruded subsequently to the Cooma gneiss, but anterior to the large pegmatite veins.

*The pegmatites.*—Pegmatite veins are distributed very widely among the crystalline metamorphic rocks, but in spite of this their relations to the surrounding rocks are by no means clear in all cases. There have been three separate igneous intrusions in connection with which pegmatites might have been injected. With regard to the blue gneiss no evidence has been found to show that there was a proper pegmatitic phase of the intrusion: it is different with the others. The schists, particularly to the south and west of Cooma, are in places very strongly injected with pegmatitic material. Owing to the fact of the mottled gneiss and the Cooma gneiss having been intruded over very much the same area, it is often impossible to tell to which intrusion these injections are due. Furthermore, both of the igneous gneisses have themselves been subjected to pegmatisation. This may be observed in the bed of Cooma Creek a few miles north of Cooma, at the head of Snake Gully near "Kiaora," and elsewhere. Long veinlets of pegmatite follow the lines of foliation of the gneiss, occasionally bulging out into lenticular masses. The sedimentary schists have been similarly affected, the little pegmatite stringers being very numerous, and following the puckerings and foldings of the schist. These veinlets are as a rule narrow, varying in width from ¼ of an inch up to a couple of inches or so, although some in the Cooma gneiss attain a width of 6 inches. They consist for the most part of quartz and flesh-coloured felspar, with subordinate white mica and black tourmaline.

Apparently distinct from these minor pegmatites, there have been observed a number of larger and more truly pegmatitic injections. The principal of these and their

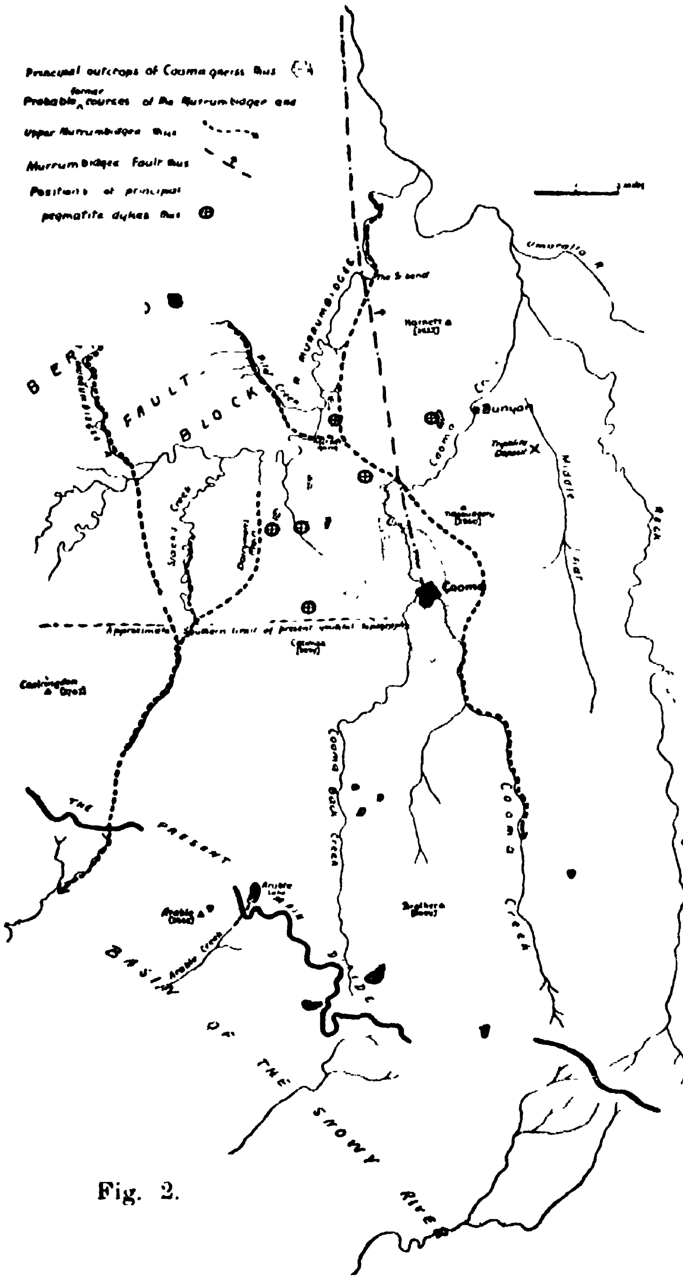

Fig. 2.

position relations to the Cooma gneiss, are indicated on the map (Fig. 2). They nearly all have an approximately meridional trend, and consist of quartz, felspar, mica and tourmaline; no other minerals have been recognized megascopically. Mr. C. F. Laseron, of the Technological Museum, Sydney, has kindly given me a piece of rock picked up by him near the Cooma pegmatite dykes, composed mainly of quartz and epidote. Unfortunately however, the relations of this fragment with the pegmatite could not be established although there is a strong probability of some connection between them.

Graphic granite is a feature of all the occurrences, and there are also coarse irregular intergrowths of quartz and felspar. Occasionally a rude "comb structure" is developed by the crystallization of large felspars growing towards the centre, the central space being filled with quartz. Mica, both white and brown, is developed, the latter sometimes being particularly noticeable along the sides of the veins with the short axes of the crystals parallel to the walls of the intrusion. Tourmaline often occurs in large segregations, but may also be irregularly distributed: in the Cooma veins the tourmaline occurs mostly along the boundary between the comb structure felspars and the central filling of quartz.

There is at times a notable local increase in the basicity of the country rock in the vicinity of a pegmatite vein, expressed by a concentration of biotite along the margin of the intrusion.

The dimensions of the veins are not in every case ascertainable, owing to the presence of a covering of soil. The occurrence west of Mittagang road appears to be about 20 feet wide, two others are 15 feet and 6 feet respectively, while those in the town of Cooma are not more than a foot or two in width. Some of them must have considerable

length: the main vein in Cooma has been traced south for about a mile, and it is probably the same which outcrops along the east bank of Cooma Creek a mile or so north of the town. None of the other outcrops have been traced for more than 150 yards.

The contacts with the invaded formations are as a rule quite sharp. In the case of the Cooma pegmatite this is very marked indeed; here a great number of veins intersect the amphibolite and the gneiss, and in each case the boundaries are very definite.

In a number of the veins or dykes there is evidence of crushing subsequent to intrusion. This chiefly affects the margins of the dykes and shows itself in jointing parallel to the walls, and in marginal granulation of the pegmatite, producing a coarse aplitic-looking and rather friable rock. Most of the dykes exhibit this to some extent, but a notable exception is the Cooma pegmatite, which remains quite massive, this being possibly due to its being in the heart of the Cooma gneiss and so more effectively protected from crushing than those dykes which are among the less resistant schists. A certain amount of ragged-looking white mica often developed in the cracks of the felspars may be secondary.

The relative proportions of quartz and felspar in these pegmatites are very variable, quartz being sometimes very subordinate and at other times the predominant mineral. The dyke at "Kiaora" is characterized by a number of elongated outcrops of quartz up to 8 or 10 yards in length, bordered by felspar and graphic granite.

*Quartz veins.*—By the decrease and vanishing of felspar we have veins of tourmaline greisen and of quartz with tourmaline. These probably represent the last phase of pneumatolytic action, and have an origin similar to that

of the pegmatites, although no actual case was found of a pegmatite vein grading into a quartz vein.

Quartz veins are very common among the altered rocks, often grooved and slickensided, and generally following the strike of the country. Some of them are metalliferous: mispickel occurs in one to the N.W. of "Kiaora," and I understand that silver was formerly mined in a quartz reef at the mouth of Slack's Creek. Some of the barren quartz reefs which outcrop may be connected with the intrusion of the Berridale granite.

The relations of the pegmatites and the gneisses, as has been said, are not at all clear. The Cooma gneiss is the most likely intrusion for the pegmatite to be connected with, but it may be noted that on the hill behind the R.C. Church in Cooma, the pegmatites intrude the amphibolite, which in turn appears to intrude the Cooma gneiss. Moreover the well-defined boundaries of the veins would indicate the intrusion of the pegmatite after the complete solidification of the invaded rocks. On the whole, however, it seems most reasonable to suppose that the injections represent the pneumatolytic phase of the Cooma gneiss. As for the minor pegmatites—those narrow stringers which seam both gneisses and schists—it is hard to say whether they are all to be correlated as phases of the Cooma gneiss magma or not.

The very striking, though not constant, association of pegmatite and amphibolite suggests that these two may represent complementary differentiates from the magma of the Cooma gneiss. This, however, is a matter which can only be determined, if at all possible, by laboratory investigation.

(b) Ordovician.—While it is not intended at the present juncture to discuss the relations of the metamorphic series with the other formations, it may be remarked here that

there are strong indications of a gradual passage from the crystalline schists through phyllites to Ordovician slates. Going due west from Kiaora homestead, one notices that the Slack's Creek phyllites appear to grade into dark micaceous slates which become less micaceous and more like ordinary slate. At McCarty's Crossing, near the junction of Bridle Creek and the Murrumbidgee, are bands of hard dense blue-black slates interbedded with whitish-grey felspathic-looking slates, and dipping east. The black slates contain obscure marks of graptolites, which have been identified as such by Mr. W. S. Dun. Lithologically these slates are similar to those interbedded with the phyllites on Slack's Creek, and appear to be of the same age.

Going west along the Adaminaby road slates similar to those at McCarty's crossing are found to occur as far as Wambrook Creek. I was unable to examine in detail the slates occurring here, but Mr. C. F. Laseron has kindly shewn me specimens of slates containing well-preserved graptolites, found by him some distance up Wambrook Creek from the road, and exhibited before the Linnean Society in 1909.[1] Mr. Laseron has also very kindly furnished me with the following list of the graptolites represented:—*Diplograptus foliacius* (very abundant), *Climacograptus bicornis*, *C. hastata* (very abundant), *Dicellograptus elegans*, *D. caduceus*, *D. affinis*, *(?) Pleurograptus*.

These slates are chiastolite-bearing, the presence of this mineral being due to contact metamorphism of the slates by the intrusion of the Berridale granite.

Following the Adaminaby road past Wambrook Creek one meets with a succession of rotten slates, and farther on of quartzites, extending right on to the outcrop of the Berridale granite, about 14 miles out from Cooma. These

[1] Proc. Linn. Soc. N.S.W., xxxiv, 1909, p. 118.

rocks are assumed to be Ordovician, as by their strike they are somewhat to the east of the Geygedzerick Hill slates mentioned below.

Dense black slates outcrop between Cooma and Bunyan, and at Bunyan to a distance of 400 yards east of the Sydney Road. No fossils have so far been discovered in them, but their marked contrast with the Silurian slates farther to the east, and their lithological similarity to those west of Slack's Creek, seem sufficiently striking to determine their age as Ordovician. The exact eastern boundary of these slates is not known, its determination being rendered difficult by the quartz-porphyry intrusions, by cappings of basalt, and by the recent alluvials of Cooma and Middle Flat Creeks. However there is a distinct difference in appearance between these slates and those outcropping further to the east which are definitely Silurian, so the Ordovician may be taken as having its eastern boundary approximately as given on the map.

At Bunyan these slates have been locally silicified, or replaced by silica, with retention of their original cleavage and other characteristics. This I can only ascribe to the intrusion of the white gneiss: traversing across the strike one observes all gradations from evident gneiss to equally evident silicified slate; there is no distinct line of demarcation between them.

Although they are not included in the map, and are somewhat beyond the area dealt with, some mention must be made of the Ordovician slates of Geygedzerick Hill, 2½ miles N.E. of Berridale. I am indebted in the first instance for information as to their existence to Mr. L. Grater, a science student at the University of Sydney, who kindly gave me some specimens of the slates which he had picked up on the spot. The hill, or rather ridge, looks to be the end of a tongue of slates and quartzites almost surrounded by

granite, the quartzite being mostly on the lower slopes nearest the igneous rock, while the slates appear on top of the ridge. Contact metamorphism has produced a very dense black slate, only imperfectly cleaved, and exceedingly rich in chiastolites. These vary very much in size, some being of microscopical dimensions, while others are upwards of 1½ inches in length. In spite of the alteration which they have undergone, the slates contain a great abundance of fairly well preserved graptolites, *Tetragraptus*, *Didymograptus* and *Diplograptus* being recognized. The presence of these fossils in such a good state of preservation here and elsewhere, denotes that the cleavage planes of the slates coincide with the bedding-planes of the original sediments.

It is interesting to note that the presence of chiastolites in the slates of Geygedzerick Hill was observed by Rev. W. B. Clarke in 1851,[1] though, curiously enough, he seems to have failed to notice the graptolites, in spite of the fact that, on his own testimony, he was ever on the lookout for them in the slates of New South Wales.

A small patch of dark blue limestone is interbedded with the slates at Pearman's Hill. The outcrop is not more than 15 yards long by about 5 yards wide. The rock shows signs of great compression, and is crystalline; possibly this is due to the presence of the white gneiss a few yards away, that is of course, if the latter is really intrusive. A diligent search failed to reveal any fossils in the limestone.

According to David, Helms and Pittman,[2] the Ordovician rocks extend about 6¼ miles to the west of Berridale, where they are intruded by the Kosciusko granite. It is interesting to note that Mr. C. F. Laseron has recently[3] found

[1] Southern Goldfields, p. 115.
[2] Proc. Linn, Soc. N.S.Wales, xxvi, 1901, p. 30.
[3] Personal communication from Mr. Laseron.

graptolite-bearing beds in the neighbourhood of Cobargo, which lies about 44 miles from Cooma in a direction roughly 10° S. of E. The slates are identical in appearance with those of Geygedzerick Hill and Wambrook Creek. The following forms were determined by Mr. Laseron:—*Diplograptus foliaceus*, *Climacograptus*, *Dicellograptus* (?) *gracilis*, *D. affinis*. It would be interesting to trace the relations of these rocks to the Ordovician of Cooma and Berridale. The interposition of Silurian sediments to the east of Cooma suggests their deposition in a trough or synclinorium of Ordovician rocks.

(c) SILURIAN.—As the Ordovician lies, roughly speaking, to the west of Middle Flat and the Silurian to the east, and as, in spite of some discordances, the prevailing dip is towards the east, it is natural to assume that the upward sequence, or the sequence of deposition, for the Silurian beds is from west to east. That being so, the lowest sediments are slates, with interbedded limestone and brown quartzites, passing upwards into gritty sandstones, carbonaceous shales and quartzitic sandstones alternating with bands of clay-shale. The limestone, carbonaceous shales and gritty sandstones are fossiliferous; the other horizons are barren.

The slates vary in colour, and are extremely cleavable and much jointed, splitting readily into small pieces. Their stratigraphical position is sufficiently determined by their association with the other fossiliferous beds.

The limestone runs in a general N.N.W. direction and forms a belt about 4 miles long. Its northern end, which disappears under the alluvials of Cooma Creek, has a width of outcrop of over 1,000 yards; this gradually decreases as one goes south, till at Toll Bar Bridge it is not more than 100 yards. The main mass disappears here, but the belt continues southwards as a series of small isolated

lenticular patches, the most southerly of which crosses the Greenhill Road a little to the west of Rock Flat Creek. Here there are seen to be two intermittent outcrops of two distinct kinds of limestone, separated by slates, and sometimes 40 yards apart. The main outcrop is of light blue limestone, massive and fossiliferous, the other harder, of a deeper blue, flaggy, unfossiliferous, and much intersected with veins of white secondary calcite. Occasionally this band is broken up into smaller bands, about 4 inches wide, interbedded with the slates. The limestone is traversed by cracks or joints striking a little west of north. The dip appears to be easterly on the western side, and westerly on the eastern, the angles in both cases being very high. Caves are said to exist in the limestone, fairly extensive and containing stalactites.

The main outcrop of the limestone is constantly attended by quartz-porphyry on both sides, which has very probably intruded and to some extent destroyed part of the limestone. A certain amount of assimilation may have taken place; a specimen of quartz-porphyry collected from near the junction showed under the microscope numerous little patches of what look like epidote. Along the eastern boundary of the limestone, however, the quartz-porphyry (and possibly the limestone too) has been converted into a kind of ironstone, thus destroying any evidence of contact effects. This ironstone is indeed more or less characteristic of the limestone outcrop, and where the latter cannot be traced ironstone is often found. The occurrence is suggestive of a metasomatic replacement.

There is in the limestone abundant development of *Favosites*, both the large massive and the small dendroid species, also *Heliolites*, *Tryplasma*, *Pentamerus*, and *Stromatopora*. The fossils are in general well preserved.

East of the limestone there is a further development of slates. Between Rosebrook homestead and the Umaralla

River the rest of the sequence is well shown. One passes in succession over grits, carbonaceous shales and quartzitic sandstones interstratified with shales in bands up to a foot in thickness. These are vertical at first but towards the river they have a westerly dip which decreases to 56°.

*Rhynchonella* in great abundance, *Strophomena*, and (?) *Tryplasma* have been found in the grits and carbonaceous shales. The fossils are a good deal compressed, and their species are indeterminate.

(d) POST-SILURIAN BUT PRE-TERTIARY.—To these rather wide limits are referred three apparently independent occurrences of igneous rocks, the quartz-porphyries, the Berridale granite, and the Myalla Road syenite.

*Quartz-porphyries.*—This is a general term employed to denote a series of intrusions with many differences both textural and mineralogical, but evidently of common origin. They outcrop along roughly meridional lines, and so far have not been found west of a north and south line through Cooma, but intruded among the slates and other sedimentary rocks to the east and north-east of the town. Southward they disappear under the Tertiary basalt, to the north they have been traced as far as Bredbo, 20 miles from Cooma, where their extent is very great. They have played a considerable part in determining the contours of the present land surface, for, as one goes east from Cooma, it is observed that, generally speaking, the porphyries form a series of parallel low ridges, while the valleys in between have been cut out of the softer and less resistant slates. The porphyries are perhaps best described as irregular dyke-like intrusions into the slates, although the outcrops attain a width of about half a mile in places. Their intrusive nature is abundantly proved by inclusions of the intruded slate, as well as by the tapering terminations of the outcrops. Very little contact metamorphism is observable, barring a little local induration of the slates.

The rock has been subjected to pressure subsequently to its consolidation; this has caused a good deal of shattering and alteration, in some cases changing the original appearance almost beyond recognition. From a field examination of the porphyries it has been concluded that there must have been at least three distinct series of intrusions, possibly four. There is first of all the very much sheared type, exemplified in the Bushy Hill formation, now reduced to what Van Hise would call a quartz-porphyry slate,[1] quite schistose in structure. The cleavage pieces have a somewhat greasy lustre, with dark green colour and greasy feel, due possibly to the development of chloritic minerals. Frequent eyes and lenticles of unshattered quartz, the relics of former phenocrysts, are scattered about the rock. Doubtless a certain amount of alteration is to be attributed to the mineralised waters which percolated through the porphyry at this place. Northwards right along the line of the Bushy Hill outcrop the porphyry is much "mylonized," in places so much so as to be recognizable only with difficulty. On Bushy Hill the cleavage planes are vertical, and no where has the departure from the vertical been found to be more than 40°. Very little in the way of ferro-magnesian constituents has been observed in the Bushy Hill porphyry. In addition to quartz, felspar occasionally appears as phenocrysts.

Between "Rosebrook" homestead and the Umaralla River one passes over a couple of outcrops of porphyry of a light grey colour, with large and abundant phenocrysts of quartz, felspar, and a dark green chloritic-looking mica in small hexagonal plates. This rock is rather shattered; it is intruded among Silurian slates and appears to be of no great extent. In the size and abundance of its quartz crystals it much resembles some of the "mylonized"

[1] A Treatise on Metamorphism, p. 779.

porphyry, and may possibly be the unaltered equivalent of this latter. In general appearance and mineral constitution it also bears a striking resemblance to a quartz-porphyry from Yass district, with which indeed it may be genetically connected.

Closely associated with this Rosebrook porphyry is a dark blue exceedingly compact felsitic rock, with relatively small development of phenocrysts, which are mainly quartz. By weathering and bleaching this rock assumes the appearance of a quartzite, as at Toll Bar Bridge. From here to Rosebrook it forms a considerable part of the eastern boundary of the limestone; it is entirely free from shattering. A ridge of the same rock is to be seen near Rock Flat, proving for it a meridional extension of at least 16 miles.

Another variety of porphyry, which is found to the east of Cooma and north as far as "Rosebrook," is a dark rock with much smaller and very abundant phenocrysts of quartz and felspar; at first sight the rock appears to be tuffaceous but this is not so. It is in all cases highly and irregularly jointed, and very often shows a rude cleavage. On the appearance of the rock in the field one would pronounce it to be of an entirely distinct type from the Bushy Hill and Rosebrook porphyries, the chief differences being the smaller grainsize of the phenocrysts and the greater abundance of felspar.

The remaining type of porphyry has evidently been intruded last of all, and has been subjected to very much less crushing than the other varieties. It is to be found on the Greenhill Road about two miles out from Cooma. Though just a little east of the line of the Bushy Hill outcrop, and west of some of the small-grained porphyry, the rock is here quite massive and free from shattering, proving its relative youth. The same porphyry also occurs farther to the east along the road to "Nitholme" and on the Kydra

Road at and past Middle Flat. Going about a quarter of a mile N.N.W. from "Nitholme," one observes that this porphyry is intrusive into the fine-grained variety; the outcrop is very wide, about one-half to three-quarters of a mile in places. Generally the rock is massive, but sometimes it is a bit shattered at the periphery of the mass. Its intrusive character is shown near Rosebrook, where an isolated outcrop of it forms a conical hill sharply differentiated from the other porphyries and from the slates.

This porphyry is a very handsome rock, abundantly porphyritic in quartz and felspar, usually also with hornblende in varying amount. Quartz-porphyry was found in which practically all the base had been replaced by oxide of iron, leaving intact only the porphyritic quartz and felspars, and again in another place kaolinization had occurred, resulting in a soft white rock studded with quartz grains.

*Berridale granite.*—Only a very small portion of the whole area of this was examined, and then not in great detail. It was only studied where it touched on the main area investigated.

As one goes from Cooma to Berridale the granite is first met about 9½ miles out. Great rounded monoliths of it strew the plain, and it can be seen stretching for a considerable distance on either side of the road most of the way into Berridale, the outcrop being occasionally concealed under small residual patches of basalt. On the Cooma side, the junction of the granite with the intruded Ordovician slates and quartzites has been to some extent eroded, and is masked by alluvial.

The granite was also met with along the Adaminaby road at a point 14 miles from Cooma, but a journey of 20 miles south on the Bobundarah road failed to reveal any signs of it, so evidently the boundary of the outcrop takes a sweep to the south somewhere between the Berridale and Bobundarah roads.

The rock is a typical biotite granite and it exhibits considerable variation both in grain and in the proportions of ferro-magnesian minerals present. This variation is of the usual type, that is with decreasing basicity and coarser grain inwards from the margin of the intrusion; this is well exhibited as one proceeds from the margin of the mass towards Berridale. A slight but distinct gneissic foliation, apparently primary, was noticed at one place, but the extent of this phenomenon was not traced. Basic segregations are fairly numerous, and a number of aplitic dykes intersect the granite; some of these were entirely of the ordinary granular type, while others exhibited occasional graphic fabric, and others again had miarolitic cavities filled with tourmaline.

On Arable Station just on the north-eastern border of the granite occurs a dyke of a dark grey porphyritic rock, without megascopic quartz, and of rather indefinite megascopic characters. In thin section the rock is seen to be of lamprophyric type.

At every place where the edge of the granite was encountered a selvage of quartzite of varying width was found, while large quartz dykes were, as might be expected, very common. The quartzite border was noticed on the Adaminaby Road, on the Berridale Road and south of it, on Arable Station, and at Geygedzerick Hill. Contact effects were not specially looked for, but this constant occurrence along the irregular granite border suggests that the quartzite represents a complete replacement of the original sedimentary rocks by silica from the granitic magma for some distance from the actual contact. Another contact phenomenon has been already alluded to, namely, the production of chiastolite in the intruded slates.

*Myalla Road syenite.*—Five miles along the Myalla road south from Cooma, there is an isolated outcrop of syenite

of boss-like appearance. The mass is over two miles long, with a maximum width of a little under two miles; it is surrounded on all sides by schists and olivine basalt, and is 7 miles away from the nearest outcrop of Berridale granite. The syenite is in general massive, and weathers into great rounded tors like granite, which undergo a kind of spheroidal exfoliation. Jointing is developed at times: one reading on a joint plane gave its dip as 65° in a direction E. 10° S. Megascopically the rock would be called a syenite, as it is seen to consist of felspar (orthoclase) and hornblende, but a microscopic examination would place it rather among the quartz-monzonites. Towards the eastern periphery of the mass there is a considerable development of a porphyritic facies, which might be called a syenite-porphyry. Irregular basic patches without any definite sharp boundaries are also frequent.

The plutonic rock is intersected by dykes of felspar-porphyry or bostonite, with only very small traces of ferro-magnesian constituents, and many apophyses radiate into the surrounding country. One of these forms a conspicuous feature among the schists along the Myalla road, and can be traced for about 6 miles, ultimately coming to an end in a railway cutting a mile north of Cooma. The texture of this dyke-rock changes as we get away from the parent plutonic mass. The felspar phenocrysts may be upwards of half an inch in length and very numerous, the base being fine-grained but evidently holocrystalline. Farther away the base gets exceedingly fine-grained and phenocrysts are very much fewer and smaller, the rock giving the impression of a trachytic lava rather than of a hypabyssal rock, while the subordinate ferro-magnesian constituents have completely disappeared. These variations are evidently functions of the distance from the parent magma, the conditions of consolidation, and especially of heat, as we get

away from the syenite, gradually becoming less and less plutonic in character. The actual contact of the syenite with the older rocks is covered over by basalt or alluvium, so it was not possible to obtain any information as to the nature and amount of the contact metamorphism or the form of the intrusion.

*Geological age of the igneous intrusions.*—There are no means of determining with exactitude the geological age of all these intrusions, nor indeed is there any direct evidence to show that they are genetically connected, or even contemporaneous with each other. It will be observed on referring to the map that the syenite is a long way away, and quite isolated from the granite, and that the porphyries are far removed from both.

With regard to these porphyries, if they all belong to the same series they must be Post-Silurian, but if not, then some may be as old as the Ordovician. Very much mylonized porphyries, hardly recognizable as such, occur in among the Ordovician slates at and north of Bunyan, and it is possible that here they represent contemporaneous submarine sheets interbedded with, and subsequently tilted and compressed along with, the original sediments. On the other hand, others of the porphyries have all the appearance of intrusions, fragments of the intruded slates being included, and slight alteration of the surrounding rocks being produced. The form of the outcrop too, in many cases, suggests a tapering sheet or sill. The intruded formations in these cases embracing Silurian beds, the porphyry must be of later age. Some of the quartz-porphyry, since it is relatively unshattered, must have been injected after the folding and compression had practically ceased.

The granite and the syenite are both clearly later than Silurian, as they have been subjected to strain only to a slight extent. The granite along its marginal portions and

the syenite throughout its observed extent are free from gneissic structures, indicating that their crystallization took place during a period of comparative crustal stability. Since the Carboniferous appears to have been a time of intrusive igneous activity in central and southern New South Wales, it seems not unreasonable to assign these igneous rocks tentatively to that period.

(e) TERTIARY AND RECENT.

*Olivine Basalt.*—The latest evidences of igneous action about Cooma are to be found in the extensive flows of basalt which cover a considerable area of the surface of the country, and must have had a very much greater extent before erosion and denudation reduced the capping to its present dimensions. Besides the large sheets, isolated residual patches of basalt, forming the characteristic table-topped hills, are to be found overlying the Berridale granite, the schists, and the slates and other Palæozoic rocks. Of the highest basalt residuals—the three hills known as The Brothers, about eleven miles south of Cooma—the Middle Brother is 100 feet higher than the next highest Trig. Station in the district, and about 700 feet above the general level of the country, but these figures of course do not necessarily indicate the depth to which the whole country was originally covered with basalt. The basalt has a much greater extent to the south and S.E. of Cooma than to the north; it may be seen practically all the way along the road from Cooma to Nimitybelle and as far as Bombala. There is evidence of a number of successive flows, in the shape of terraced hills, sometimes as many as four terraces being distinguishable. Again occasionally one finds a flow of fresh basalt on top of an older and much decomposed flow.

On the summit of the North Brother, and also, I understand on the Middle and the South Brother, the basalt is

prismatically jointed over a space of two or three acres. The columns are remarkably regular, mainly hexagonal in section and up to 18 inches in diameter, and no columns were observed more than 4 feet long. In texture the rock is exceedingly fine, and olivine occurs in nodules or segregations, in much greater proportion than in the normal basalt. In places there has been a tendency to subsidiary jointing, producing a kind of pisolitic effect on the weathered surface. Only the summit of the North Brother is composed of this very compact basalt; below it the hill is terraced and the basalt is of the ordinary fine-grained type.

A noteworthy example of variation in the texture may be observed west of the Myalla Road 4 miles south of Cooma. Here there is a flat-topped terraced ridge, the topmost terrace being of coarse-grained basalt, doleritic in aspect and microscopically seen to have ophitic fabric. The basalt of the terrace immediately underneath is much finer in grain and of granulitic fabric. Two possible explanations suggest themselves. What we now see as the upper terrace may really represent the bottom part of a thick flow, whose top has been denuded; the bottom part would have cooled comparatively slowly and so have become somewhat coarsely crystalline. Or else the coarse-grained rock might have been intruded as a kind of dolerite sill between two pre-existing flows, one of which is now denuded away.

To the N.W. and east of Cooma the basalt has in some instances filled old pre-Tertiary valleys; for example, the road from Cooma to Murrumbucca viâ Mittagang Bridge runs mostly along such a valley for 11 miles, and the former course of the Upper Murrumbidgee from McCarty's Crossing to the junction of the Dalgety and Berridale Roads is now marked by flows of basalt. No tuffs have been anywhere found associated with any of the flows.

The age of the basalts, and the possibility of their extrusion having continued into recent geological times, will be discussed later in connection with the physiography.

*Diatomaceous earth.*—There is a deposit of diatomaceous earth or tripolite about $1\frac{1}{2}$ miles E.S.E. of Bunyan Railway Station (See Fig. 2). The deposit is referred to in Pittman's "Mineral Resources of N. S. Wales," p. 429, also in the Records of the Geological Survey of N. S. Wales, 1897, p. 128.

From test-holes which have been put down, the deposit is believed to cover an area of 30 acres. It is situated in a hollow on the western side of Middle Flat, surrounded on the north and west by a ridge of slates and mylonized quartz-porphyry capped by Tertiary basalt. The deposit is close to the surface, being covered by 18 inches to 2 feet of alluvium, chiefly basaltic soil. Under this is about 2 feet of very hard buff-coloured "mullock," a kind of travertine containing numerous angular fragments of quartz and of diatomaceous earth. This is succeeded by another 2 feet of massive tripolite of a pale creamy-white colour, then comes 3 feet of layered tripolite—"slate," as it is called—which is slightly denser than the other and shows stratification. Under this the deposit is alternately massive and stratified. At intervals, pipes of roughly elliptical section occur, filled with a hard, brittle brown clay, in which remains of bones, etc., are often found. Veins of wood opal are fairly frequent, yellow, red, and green in colour, and very light and brittle. The deposit is being worked, but not in systematic fashion, digging operations not being carried on to a greater depth than 10 or 12 feet.

*Travertine.*—At Rock Flat, 9 miles S.E. of Cooma, on the right bank of the creek, are situated the well-known Rock Flat mineral springs,[1] where carbonated waters rise

[1] For an account of these see Rec. Geol. Surv., N.S.W., 1889, p. 179.

from a depth and flow to the surface. Although at present only one spring—a chalybeate one—is actually flowing, it is only of recent years that the spring which is the source of the present supplies has ceased to flow, and there is evidence that in the past quite a number of springs were active. A considerable amount of travertine has been deposited from these springs, and is still being formed. So far the deposit has a maximum depth of 12 feet, and is said to cover an area of 5 acres. Except at one point where the creek takes a sharp bend to the east, the travertine is wholly on the east or right bank of the stream. The Rock Flat Springs are at the base of a great quartzitic outcrop, from which the place takes its name. The outcrop consists of sandstone on edge, intersected with quartz veins, and which merges into quartzites towards the west, and ultimately into a kind of quartz breccia, the cementing material being also quartz. The dip of the quartzite is about W. 10° S. at 40°.

Travertine is found sparingly developed in other parts of the region; it has been noted along the Bobundarah Road near the North Brother, also just south of Bunyan along the Sydney Road. It occurs on top of the old metamorphic rocks, and is generally covered by alluvium. Probably it is post-Tertiary in age.

A curious occurrence was found in Butler's Creek, a bit north of Mittagang Bridge. Here the creek, when running, tumbles over a rock-bar about 12 feet high, and down the face of this there is a kind of stalactitic deposit of travertine, evidently formed when only a trickle of water was running, and due to evaporation as the water flowed over the heated rock in summer.

*River gravels.*—Perhaps the most extensive development of these is along the Numeralla Road to the west of the Toll Bar Bridge over Rock Flat Creek. The gravels com-

mence three-quarters of a mile from the creek, and form a very striking feature of the topography, extending half a mile to the south and much farther to the north. They are composed principally of boulders and pebbles of brown quartzite and white quartz. The quartzites are up to 18 inches in length, and there are occasional boulders of nearly three feet in diameter. They all show a good deal of rounding and smoothing and occasionally of polish. Low mounds of gravel and other alluvium are to be seen in the vicinity, and similar accumulations may be observed in the broad flat valley north of the limestone belt. There is little doubt that these gravels belong to Rock Flat Creek or an ancestor of it; their presence at a distance of three-quarters of a mile west from the present bed of the creek, and at least 100 feet higher, would indicate a good deal of migration and erosion on the part of the creek since their deposition. It is rather puzzling to find these gravels, and especially the boulders of three-foot diameter, on the highest point of the ridge separating Middle Flat from Rock Flat Creek. I was at first inclined to ascribe their presence to ice-transport, but doubtless they are fluviatile deposits.

Three well-formed crescent-shaped alluvial terraces mark the point near Pearman's Hill where with a sharp S-bend the Murrumbidgee emerges from the Berridale fault-block. The highest is at 130 feet, and the others at 50 and 25 feet respectively, above the present level of the stream. These terraces are of gravel principally, but the middle one is mostly mud.

*Æolian deposits.*—A noticeable feature of the Sydney road between Cooma and Bredbo is the great extent of country partially or wholly covered with drifting sand. Shortly after the road crosses Umaralla River, this sandy country begins, and it continues to within 5 or 6 miles of Bredbo. This mantle of sand gives the region a barren and

desolate appearance. It is due to the disintegration of quartz-porphyry, of which there is a very extensive development along the road to Bredbo. The shifting of the sand by the action of the wind has the effect of drifting up the road in many places, of burying fences, and of destroying vegetation.

*Quartzitic conglomerate.*—At various points in the Cooma district one comes across outcrops and boulders of a silicified quartz-conglomerate, apparently forming a surface capping to the slate, etc. Just north of the Myalla Road syenite masses of this conglomerate are seen, and here too we get a dense bluish-grey quartzite, evidently connected with the conglomerate. No evidence could be found as to the age of these occurrences, or their relations with other formations: they are probably the result of deposition from silica-bearing solutions, but whether these were connected with the late igneous intrusions, or are of much more recent date it is impossible to say.

## III. Economic Geology.

*Bushy Hill.*—The Bushy Hill gold mining field is dealt with in the Annual Report of the N. S. Wales Department of Mines for 1898. A number of references are made to it there, including the report of the Chief Inspector of Mines, with petrological appendix by Mr. G. W. Card.

The occurrence of gold at Bushy Hill was noted about 16 years ago, and a certain amount of mining work was done, but, though some good results were obtained, for various reasons work was abandoned almost completely. Gold, copper and lead ores have been obtained. In the old days only the gold was sought after, some good values being obtained from the surface free gold. Telluride yielding high percentages was found, but not in great quantity. The copper occurs as auriferous pyrites, apparently in considerable quantity in places. At present copper is being

extracted from the water in some of the old shafts by the simple method of throwing in scrap-iron, which is in time replaced by metallic copper. Galena is said to have been found on the hill.

Bushy Hill, which is really a long ridge, is composed mainly of a mylonized quartz-porphyry which forms the country rock, and the minerals occur mostly disseminated through it. The porphyry contains numerous "eyes" of quartz, while less frequently felspar occurs as phenocrysts. Slates also form part of the country rock. The cleavage planes of quartz-porphyry and slates are vertical. On the Cooma side there is quartz-porphyry which appears to be of a later date than the other: it is free from crushing, has smaller phenocrysts, and has a siliceous-looking base, resembling to some extent the silicified porphyry at Toll-Bar Bridge. North of Bushy Hill a long sinuous outcrop of quartzite, running in general N. 20° E. extends to near the Numeralla Road.

Between Bushy Hill and Middle Flat is a long reef, forming a conspicuous ridge about half a mile long, and composed of what appears to be a kind of quartzite, seamed with quartz veins. This reef has been found to be barren.

*Tripolite.*—Reference has already been made to the deposit near Bunyan. This is being worked by a company which employs one man in digging the tripolite, drying and bagging it, and despatching it to Melbourne, for what ultimate purpose I have been unable to ascertain.

*Lime.*—At Toll Bar Bridge there is a kiln where the limestone is being burnt on a small scale. There is apparently only a local sale for the lime, but there seems no adequate reason why a bigger industry should not be built up.

*Barytes.*—Abont 200 yards east of the N.E. corner of Portion 300, Parish of Cooma, and just outside the eastern

municipal boundary, there is a vein of barytes in shattered quartz-porphyry. The vein has a maximum width of 14 inches at the surface, but I understand it widens considerably as it is traced downwards. The dip is at 50° in a direction E. 19° N., which is more or less in conformity with the cleavage of the quartz-porphyry. The outcrop was traced by me for a distance of about 30 yards. A little excavating has been done and some of the barytes removed, but the work has not advanced beyond the prospecting stage.

### IV. Age of the Metamorphic Series.

The stratigraphical position of the crystalline complex consisting of the schists, phyllites and quartzites, intruded by the mottled, Cooma, and blue gneisses, is a matter which has exercised me very much without any definite conclusion being reached. At the present stage of the work it is perhaps a trifle premature to discuss the matter fully. In the first place it is only in the area round about Cooma that the field relations have as yet been studied, whereas there is reason to believe that this crystalline series extends considerably farther north than Pearman's Hill, the northerly limit of my investigations up to date; an examination of this northerly extension may perhaps result in the discovery of some conclusive evidence. Secondly, field evidence may quite possibly be supplemented by laboratory investigation, and this latter is by no means complete. However, I have thought it good to make some mention here of this most important question.

The principal difficulty, and it is a great one, which confronts anyone attempting to delimit the various formations around Cooma lies in the fact that no stratigraphical breaks are to be found, the whole of the old Palæozoic rocks being so intensely folded as to obliterate all traces of original unconformities, if such existed. The prevailing dip of planes of schistosity and cleavage is easterly, but many

reversals are found. High dip-angles are the rule, and the cleavage planes are often vertical. Possibly the present state of affairs results from the erosion of a series of isoclinal folds. On the slopes of ridges one occasionally found discordances of dip—beds on one side dipping towards those on the other side, apparently indicating a fold-trough, but in some instances this was clearly seen to be merely a surface phenomenon, the beds, originally vertical or nearly so, inclining over towards the downhill side of the ridge under the influence of gravity.[1] Nothing but extremely detailed mapping of individual horizons could determine the nature of the folding.

With regard to the metamorphic series, the gneisses are quite definitely intrusive into the schists, and the question of age therefore centres round these schists and the phyllites. A number of traverses were made across the strike, both to the east and west of the axis of the complex, and in no case could an abrupt transition in the rock-type be found. Starting from Kiaora homestead, on crystalline schists, as one goes west the rocks become more micaceous and phyllitic in appearance: there is a considerable belt of these rocks, about 1½ miles wide, which I have named the Slack's Creek phyllites from their typical development and the good sections shewn there. Near the Dry Plain road and beyond it to the west, the phyllites have graded into micaceous slates which are in the same line of strike with the slates in which graptolites occur at McCarty's Crossing, about a mile to the north.

On the eastern side there is the same gradual passage from schist through phyllite into micaceous slate, but here the transition belt is not so broad, practically no knotted phyllite is developed, and there is the intrusion of white gneiss which interrupts the succession of the beds.

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[1] Mr. E. C. Andrews informs me that he too has found this 'false dip,' as it may be called, troublesome in the field.

Again, as further evidence, as has been stated above, at Bunyan the Ordovician slates are silicified for some distance out from their contact with the white gneiss. Now this white gneiss is closely associated with the blue gneiss, and this would go to show that the gneiss is later than these slates.

It has been urged that strike faulting could have thrown down the Ordovician slates against the Pre-Cambrian schists, but in this case the problem of the transitional phyllites becomes insistent of solution. Of course it may be argued that, as no definite junction between Silurian and Ordovician can be found, any original unconformity between Ordovician and older formations would likewise be obliterated. But on the other hand the Ordovician and Silurian can be separated on fossil evidence, whereas there is nothing but gradual change of lithological characters to differentiate the schists from the slates.

So far as I can interpret it, the evidence available would point to the fact that we are dealing with an area which has been affected by both regional and contact metamorphism. The gneisses have been intruded successively and crystallized under conditions of great pressure; the schists would then be caused by contact metamorphism of the slates in the vicinity of the gneissic intrusions, the intensity of the metamorphism gradually diminishing outwards. It is plain that there is a much greater extent of gneiss than indicated by the outcrops, and in such case the underground extension would go to the west principally. The suggested broad relations between the metamorphic rocks and the other formations of the area are shown in Fig. 1.

I am quite aware that the hypothesis here advanced raises serious difficulties, but at the same time it is to be understood that the evidence so far gathered is by no means regarded as conclusive; nothing at all final can as yet be

stated about the question, and of course it is very doubtful whether the matter will even be settled by future investigation.

### V. Geological History up to Tertiary Times.

We can to some extent trace the sequence of the events which have formed the geological history of the region. In Ordovician times the whole extent of the country was a great sea, in which sandy and muddy sediments were deposited to a considerable thickness: later, in Silurian times, marine conditions still obtained over part of the area at any rate, with deposition of limestones, shales, sandstones and grits. These last would appear to mark a change to shallower water conditions, possibly indicating a positive movement of the earth's crust. Uplift of the area followed, with great earth movements and intense folding along a nearly meridional axis. What was in Silurian times a sea now became dry land, and has not since been submerged.

Subsequently to this uplift, during Devonian or Carboniferous times, intrusions of porphyry, granite and syenite took place. Very extensive denudation and base-levelling must have occurred, and was probably repeated as a result of successive uplifts, so that before the outpouring of the Tertiary lavas the physiography of the country had reached a state of considerable maturity. The granite and syenite had been laid bare by erosion, and the ancient corrugations of the Ordovician and Silurian rocks had been smoothed out by denudation.

### VI. Physiography.

The geological history from the Tertiary till now is really the history of the present topography, and is best to be learnt by considering and studying the surface of the country as it now exists.

It is to be observed that two strikingly different types of topography are presented within the area described. If two lines be drawn, one north and south through Cooma, and the other westwards from a point a few miles south of Cooma, the areas exhibiting these two types are roughly divided off from one another (Fig. 2). To the N.E. we have rugged country, intersected by deep V-shaped valleys, but with some remnants of mature physiography still visible, as for example Dairyman's Plain, the valley of Pilot Creek, and the upper part of Slack's Creek. In other words, we have an area of mature topography with youthful features superimposed. This country is mainly schists and gneisses.

The remainder of the area is generally speaking in strong contrast: it is of a gently undulating nature, characterized by wide shallow valleys running north and south, and bearing all the marks of old age. These valleys are eroded out of the comparatively soft slates, the separating ridges being largely of the more resistant quartz-porphyries.

The surface of the country is diversified by a number of elevations above the general level; such are the Blue Peak, Mount Gladstone, The Brothers (North, Middle and South), Coolringdon Hill, etc. A number of small lakes are scattered about, mostly in a belt extending for about four miles north of the Great Divide.

The drainage of the country is effected by the river Murrumbidgee and its tributaries. The Murrumbidgee, in the earlier part of its course, as seen in this region follows an approximately E.S.E. direction; it then turns sharply to the east, and flows in this way as far as Mittagang Bridge, when it turns once more, this time sharply northward, or a little east of north. Before the eastward turn the river occupies a middle-aged valley, but from this on it pursues a tortuous course in a youthful valley, between high steep banks of phyllite and schist, which in parts

descend sheer into the water on both sides. The stream continues in this young valley through schists and gneisses to a point about 9 miles N.N.E. of Cooma, where with a sharp S-bend it debouches from between its high containing walls into open country, after which it continues northward, flowing at the base of a steep escarpment which forms its western bank.

During the eastward part of its course the river receives no tributaries from the north, but on the south bank it receives Bridle Creek (with its tributaries Wambrook and Peak Creeks), Slack's Creek, Spring Creek and Snake Gully. These are all characterized, especially near their junctions with the river, by relatively steep grade and by V-shaped valleys. Slack's Creek near its source flows in a broad shallow valley, of which mention will be made later, while Spring Creek rises at the northern extremity of Dairyman's Plain, a shallow valley up to three-quarters of a mile wide. After the river turns north it receives a couple of small youthful creeks, Butler's Creek and another one, unnamed, on its right bank; on the left the only tributary of importance is Pilot Creek, which flows S.E. for 4 miles close up against the eastern side of a mature valley to within a mile of the river, when it plunges into a narrow gorge, joining the Murrumbidgee three-quarters of a mile north of Mittagang Bridge. Pilot Creek forms with the Murrumbidgee a boat-hook bend,[1] the flow of the river being directed northward, while that of its tributary is towards the south.

The drainage of the country is mainly to the north. Cooma Creek and Cooma Back Creek pursue a more or less parallel course through open country in fairly wide valleys to within 5 miles of Cooma, when they begin to converge, uniting in the town to enter a deep valley cut through the Cooma gneiss and schists. Cooma Creek emerges from

[1] Griffith Taylor, *op. cit. sup.*, p. 8.

this valley 4 miles along the Mittagang road and flows N.N.E. across a level plain to join Rock Flat Creek. Considerable alluvium marks the confluence of the two streams.

Rock Flat Creek has cut for itself a fairly wide valley. It shows evidence of having shifted its bed somewhat to the east in recent times. From about the 6-mile peg on the Kydra Road, as one looks north there can be seen a long ridge of quartz-porphyry forming the left bank of the valley evidently carved out by the creek in the past. The present course of the stream however is upwards of half a mile to the east of this ridge. Again, the gravels along Numeralla Road to which reference has already been made give evidence of easterly movement. Rock Flat Creek joins the Umaralla River 4 miles nearly due east of the S-bend in the Murrumbidgee.

The history of the present topography has been referred to by Griffith Taylor,[1] and discussed in greater detail by Süssmilch.[2] Briefly, the region forms part of what was in late Tertiary times a peneplain area—the Monaro peneplain—the occasional isolated elevations being residuals of a former peneplain—the Mount Ainslie peneplain. This Monaro peneplain has undergone differential uplift, the area in the N.W. which has been roughly indicated above forming part of the Berridale fault-block, with probably a slight tilt down towards the south, and bounded on the east by a steep escarpment—the Murrumbidgee fault-scarp, indicated in Fig. 2. This escarpment crosses the Murrumbidgee near Pearman's Hill, and continues south, gradually merging, as it nears Cooma, into the general level of the country. To the east of the fault-scarp the country has been less elevated, and farther north this relatively depressed area is rather narrow, forming the Colinton senkungsfeld. It broadens considerably towards the south

[1] *Loc. cit. sup.* [2] *Loc. cit. sup.*

and eventually merges into the Berridale fault-block to the south and S.W. of Cooma. This Colinton senkungsfeld is tilted towards the north.

It was probably the same series of earth movements as caused the faulting and differential elevation which also shifted the divide and altered the drainage system of the region. The present divide, which runs roughly E. 30° S. at a distance of about 9 miles from Cooma, is very low, and is the result of recent slight tilting of the whole country towards the N.E. The old divide is placed by Süssmilch between Bredbo and Colinton, and by Taylor at Tharwa, 25 miles farther north. Both authors are, however, agreed that the Upper Murrumbidgee used to form part of the Snowy River system, and that for the part of the river between Mittagang Bridge and the old divide there has been a reversal of flow, or in other words that this part also of the river used to belong to the Snowy system, and is now really an obsequent stream.

The above is in the main an abstract of Süssmilch's views as outlined in his extremely interesting and suggestive paper, and there can be little doubt as to their general accuracy.

It might be urged that the so-called Berridale fault-block is due to differential erosion. It is certainly remarkable that to the west of the scarp the rocks are schist and gneiss, while to the east the country is composed mainly of less resistant slates, etc., so that one might expect a greater degree of erosion to the east than to the west. And again the Berridale fault-block merges to the south into the general level of the Colinton senkungsfeld just about where the gneiss-injected crystalline schists cease.

But on the other hand we have evidence of recent uplift and dissection of the fault-block in the presence of the youthful Murrumbidgee valley, which is in places a veritable

gorge (see Plate IV, fig. 4), and in the fact that we find youthful streams flowing in old valleys, as in the case of Pilot Creek. There is no stratigraphical evidence of the fault, but the fact that we do get the same schists and gneisses on the low ground to the west of the scarp as occur on the higher ground to the east, would go to show that the scarp is due to something else than differential erosion.

On the basis of Süssmilch's conclusions I have tried to work out in some little detail the physiographic history of the area with which I am concerned.

The ancient valley of the Upper Murrumbidgee, from the point where near McCarty's Crossing it now turns abruptly east, can be traced south till it joins the broad old valley of Slack's Creek. The ancient course of the river is now blocked by thick basalt flows, and bounded by ridges of phyllite and quartzite, and its contours are in marked contrast to those of the present Upper Murrumbidgee. The latter has been rejuvenated in consequence of the uplift, and has cut down a comparatively recent gorge through its former mature bed. The old valley forms the diagonal of a quadrilateral formed by Bridle Creek and Slack's Creek on the west and east, and the Murrumbidgee and the Adaminaby road on the north and south respectively. The old river joined Slack's Creek or its south-flowing ancestor just south of the Adaminaby road, and thereafter flowed to the S.W., crossing the site of the present divide just a little to the west of the Dalgety road. The valley now known as Dairyman's Plain was probably a tributary.

With regard to the other part of the Murrumbidgee, north of Mittagang, there is less certainty. At the time of the uplift the country was in a state of very mature erosion; the dividing ridges between the broad meridional valleys had been considerably worn down and there was doubtless

much anastomosing in the river system. The probable main features of the drainage are indicated in the map (fig. 2). The mature valley now occupied by Pilot Creek marks the course of a stream which flowed across the line of the present river at Mittagang, and S.E. along the dry valley in which is the present Mittagang road, thence south of Tillabudgery Trig. Station, across the racecourse, along the valley just west of Bushy Hill, and then probably into the valley of the present Cooma Creek. This old Pilot Creek valley is marked by the remnants of a basalt flow throughout its entire length. To this valley there is a tributary dry valley starting at a point about three-quarters of a mile east of Mittagang Bridge, and running a little east of north parallel to the present Murrumbidgee to within a short distance of the S-bend in that river. This valley is cut pretty deeply into the schists and gneisses, but is fairly mature: it is now tapped and drained into the Murrumbidgee by Butler's Creek and another small creek further north.

It is extremely unlikely that the old Murrumbidgee should have flowed south through the Berridale fault-block along its present very youthful channel. More probably it originally flowed S.E. in the present channel of the Umaralla for some distance, then south along the valley of the present Rock Flat Creek, and so on to join the Snowy River.[1] When the tilting and other earth-movements occurred the direction of flow was reversed and the now north-flowing Murrumbidgee began to head back towards the south. At the S-bend for some reason or another it commenced to cut into the fault escarpment, and a new stream was formed which cut across Pilot Creek, captured its head-waters, and converted the southern portion of its bed into a dry valley.

[1] An alternative suggestion is that the river flowed through the dry valley between the S-bend and Mittagang, and down southwards through the Mittagang road valley (see Fig. 2).

How the east-flowing part of the river came into being is undoubtedly puzzling. The presence of conspicuous jointing in a direction nearly east and west, already noted, may indicate an east and west fault or buckle along the line of the river. At all events there is a downward slope from the divide to the river.

It is a noteworthy fact that while some of the valleys, as for example those of Pilot Creek and of the old Murrumbidgee south of McCarty's Crossing, are marked by flows of basalt, others such as Dairyman's Plain and the valley between Mittagang and the S-bend are quite free from basalt. It may be that certain of the valleys were more conveniently placed than others with regard to the centres of eruption, for flooding with lava.

From the depth to which the relatively mature valleys such as that of Pilot Creek have been eroded in the Berridale fault-block, and the fact that this valley when it emerges along the Mittagang road from the fault-block suffers no change of level, and from consideration of the fact that the valley between Mittagang Bridge and the S-bend is at its northern end on about the same level as the topmost alluvial terrace at the bend, one is inclined to believe that the fault-block rose very gradually, the erosion of the southward-flowing stream keeping pace with the elevation, until the formation of the new divide tilted the country down somewhat towards the north and caused the formation of the present Murrumbidgee gorge through the fault-block. It is probable that the upheaval which caused the present divide gave the country a bit of a tilt to the north-east.

*Age of the basalts.*—A very interesting question is raised by the foregoing discussion, with reference to the exact period of outpouring of the basalts. Such basaltic elevations as Tillabudgery and The Brothers probably antedated

the present Monaro peneplain. It was thought that they might have been centres of eruption, but no evidence has been found to confirm such a view. Now if these are really residuals, it follows that the extrusion of basalt which formed them must have occurred prior to the evolution of the present topography.

Again the Murrumbidgee near the mouth of Bridle Creek is seen to flow between banks which are of slate capped by basalt, as if an old valley had existed which had been filled with lava, and the rejuvenated river had cut through this and down considerably below the level of the former stream-bed.

On the other hand the basalt existing in the Mittagang road valley and that of Pilot Creek must have been extruded subsequent to the formation of these valleys, that is to say, subsequent to the uplift of the Berridale fault-block. In addition to this, the basalt hills are often terraced, denoting a succession of flows, and in various places one finds a flow of perfectly fresh and recent-looking basalt on top of an earlier and much decomposed one.

While therefore there has been no definite field evidence made available, it seems at least possible from the above considerations that the extrusions of lava, which were doubtless connected with the earth-movements, were prolonged over a considerable period or may belong to two widely separated epochs; they may even have lasted into recent geological times. Petrological work on the basalts may do something towards the elucidation of this question, and further field-work may also help to settle the matter.

No decisive evidence as to foci of eruption was discovered. It is thought that one focus may have been the head of Pilot Creek, where the valley is abruptly terminated by the scarp of a basaltic platform raised to a height of about 250 feet above the level of the valley. Of course the out-

pourings may have been in the nature of fissure-eruptions, and the absence of tuffs renders this highly probable.

*Lakes.*—Mr. Süssmilch[1] ascribes the numerous small lakes which indent the surface of the country to warping of the earth's crust as a result of the movements of elevation. They seem to be most naturally associated with the formation of the present main divide, as they occur mostly in a belt about 4 miles wide lying along and to the north of the divide. In the case of Arable Lake it seems possible that its formation was due to ponding of the headwaters of Arable Creek by the upraising of the divide.

EXPLANATION OF PLATES.

Plate II.—Geological Map of the Cooma District, N.S. Wales.

Plate III.—Fig. 1. Phyllites in Slack's Creek due west of "Kiaora," showing dip towards the east, and jointing in a direction E. 10° N.

Fig. 2. Dykes of pegmatite intersecting amphibolite, in Cooma town.

Plate IV.—Fig. 3. Outcrop of intensely crushed quartz-porphyry at Bunyan. Note the cleavage that has been developed.

Fig. 4. Wallaby Rocks, on the Murrumbidgee, about 1½ miles up the river from Mittagang Bridge. Note the youthful character of the gorge. The banks are composed of schist mainly.

Plate V.—Fig. 5. The northern portion of the S-bend, Murrumbidgee River, looking a little west of south down the U-shaped dry valley in the Berridale fault-block.

Fig. 6. Another view of the S-bend, looking east, and showing the river emerging from the fault-block. Observe the fault-scarp in the background.

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[1] *Loc. cit. sup.*

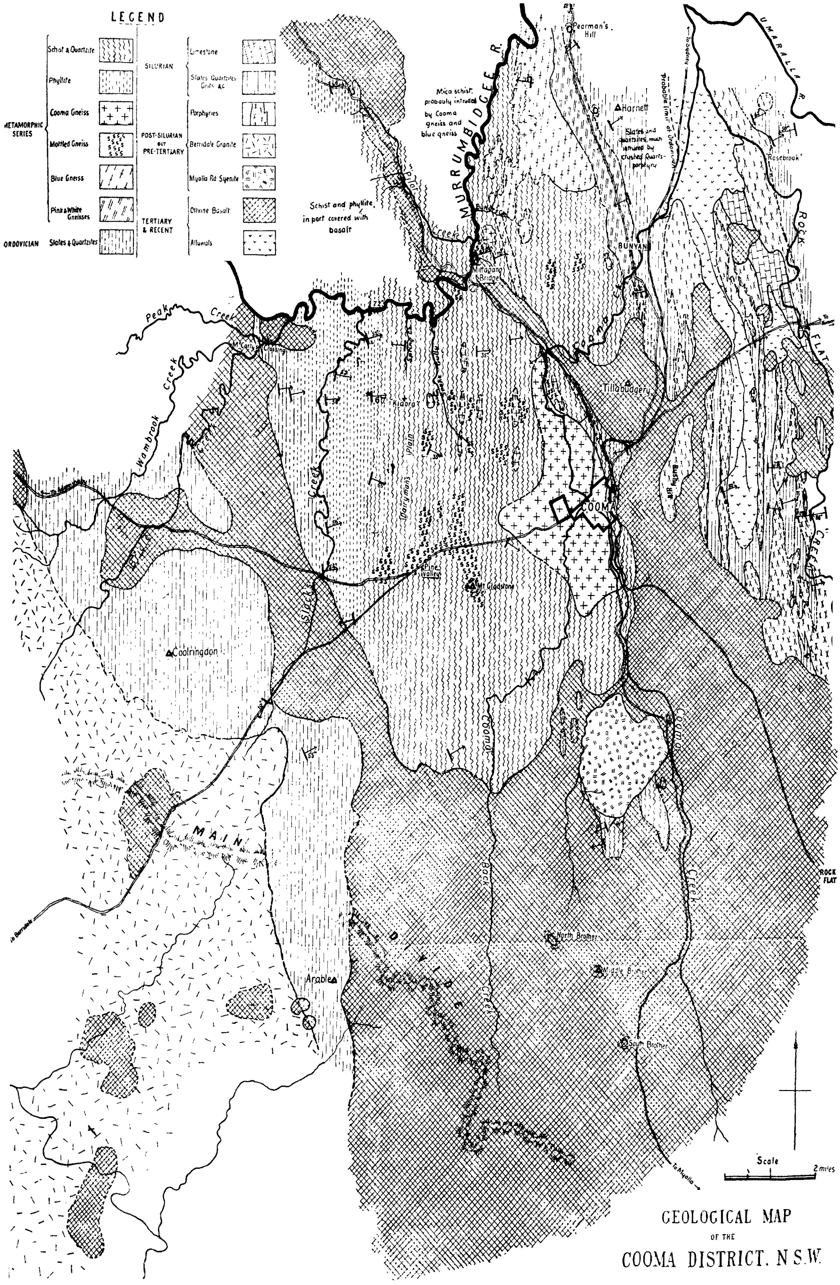
LEGEND
METAMORPHIC SERIES
Schist & Quartzite
Phyllite
Cooma Gneiss
Mottled Gneiss
Blue Gneiss
Pink & White Gneisses
ORDOVICIAN
Slates & Quartzites
SILURIAN
Limestone
Slates Quartzites Grits &c
POST-SILURIAN BUT PRE-TERTIARY
Porphyries
Berridale Granite
Myalla Rd Syenite
TERTIARY & RECENT
Olivine Basalt
Alluvials
Schist and phyllite, in part covered with basalt
Mica schist, probably intruded by Cooma gneiss and blue gneiss
Slates and quartzites, much intruded by crushed Quartz-porphyry
Probable limit of Ordovician
MURRUMBIDGEE R.
UMARALLA R.
Pearman's Hill
Harnett
Rosebrook
BUNYAN
Tuggeranong Bridge
Peak Creek
McCarty's Crossing
Wambrook Creek
Kiaora
Dairyman's Plain
COOMA
Tillabudgery
Bushy Hill
ROCK FLAT CREEK
Pine Valley
Mt Gladstone
Slacks Creek
Coolringdon
Cooma Creek
MAIN
DIVIDE
Arable
to Berridale
Back Creek
North Brother
Middle Brother
South Brother
ROCK FLAT
to Myalla
Scale
2 miles
GEOLOGICAL MAP OF THE COOMA DISTRICT, N.S.W.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

# THE GEOLOGY OF THE ERUPTIVE AND ASSOCIATED ROCKS OF POKOLBIN, NEW SOUTH WALES.

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With Plates XXV XXVIII.

[*Read before the Royal Society of N S. Wales, December 6, 1911.*]



## Introductory.

The district which it is proposed to deal with in this paper is situated in the County of Northumberland, about six miles from the town of Cessnock. The eruptive rocks lie in the Parishes of Rothbury, Pokolbin and Milfield, and comprise an area about six miles long by about two miles broad at the widest part, the longer axis being roughly north and south.

So far as we are aware, no detailed description of the igneous rocks of this district has hitherto been published. In Professor David's "Geology of the Hunter River Coal-

field of N.S.W.," Part I,[1] there are allusions to Pokolbin, and the eruptive complex is referred to as a Carboniferous inlier. A sketch map is given, and some sections indicate suggested relationships between the rocks, which are referred mainly to Carboniferous times, with some contemporaneous lava flows in the Lower Marine of the Permo-Carboniferous. This is, to the best of our knowledge, the only place in geological literature where reference is made to the igneous rocks of Pokolbin. We propose to treat the district in some geological detail, since, though it is of no very great extent, it possesses a very interesting geological history.

For convenience of treatment and reference the district will be divided into three areas:—

(i) The Drake's Hill area, extending from a point about half a mile north of the southern boundary of the Parish of Rothbury to "Maluna" homestead.

(ii) The Matthews' Gap area, from Maluna to Matthews' Gap.

(iii) The Mount Bright area, from Matthews' Gap as far south as the "Jerusalem Rock" and Mount View School, including the northern portion of Mount Bright.

These areas are by no means to be separated geologically or petrographically, as we shall endeavour to show that the rocks of the whole district, with a few exceptions, are to be considered as forming part or all of a geological unit.

**Physiography and Preliminary.**

The northern portion of the district forms a chain of foothills to the Brokenback Range, whose steep scarp runs in a general E.S.E. direction as far as Matthews' Gap, where it takes a sudden turn to the east. Continuing thus

[1] Memoirs of Geol. Surv. N.S.W., Geology No. 4, 1907.

as far as Mount Bright, it once more turns E.S.E. and follows an irregular course. The range forms part of the boundary of the old Hunter Valley, which extends for many miles to the east as a generally level plain. This range probably represents the remnant of a ge-anticline of Permo-Carboniferous rocks which had a roughly meridional axis. It is composed of Permo-Carboniferous sediments dipping to the west, capped by gently dipping Triassic sediments—the Narrabeen Series and Hawkesbury Sandstone.

At Matthews' Gap, where the range turns eastwards, the eruptive rocks are encountered, and of these the range is composed as far as the southern boundary of the district we have to deal with. Professor David considers that, subsequent to the eruption of the lavas of this district, marine conditions obtained, and the eruptive masses existed as islands or at all events as submarine elevations in the Permo-Carboniferous sea. Elevation and denudation have laid them bare again, above sea level. At present the physiography is a mixture of maturity and youth. It is evident on the one hand that a considerable amount of dissection and denudation took place before the deposition of the Permo-Carboniferous sediments, as conglomerates can often be traced filling in what were Permo-Carboniferous valleys and containing pebbles of the Carboniferous rocks. Furthermore some of the hills of to-day must be substantially as they were at the close of Carboniferous times, as we find the conglomerate dipping off their flanks with comparatively little evidence of further denudation. Drake's Hill is a case in point.

On the other hand, Post-Triassic erosion has in many places cut into the eruptive rocks, and the work of dissection is still proceeding. In the Matthews' Gap area the youthful physiography of the country is particularly evident, V-shaped valleys being formed with eruptive rocks on

either side, while the steep eastern scarp of the range from Mount Bright to Mount View also betrays youthful physiographic conditions.

Two examples of imminent stream capture on a small scale are to be seen near Matthews' Gap, within a quarter of a mile of one another, where two parallel branches of Moogering Creek are eroding back towards Flying Fox Gully which is flowing at a higher level than the other creeks, in a direction perpendicular to them and with a much gentler grade. A reference to the contour map will make evident the very short distance which remains to be eroded in both cases.

**Faults.**

Although there is evidence of extensive and complicated faulting very little can be definitely determined with regard to it. This is due to the fact that much of the faulting occurred probably as early as Mesozoic times, so that all surface evidence has long been obliterated, and the existence and position of the faults must be inferred from geological considerations.

Professor David has determined, on stratigraphical grounds, a series of faults affecting the beds of the Permo-Carboniferous, and it is quite likely that in connection with these main movements minor faulting occurred in the eruptive rocks of the district. A very marked line of faulting is that along the eastern face of the range from Mount Bright to Mount View. In fact two almost parallel faults seem to be indicated here. The evidence is both physiographic and geological. The bold scarp of rhyolite, perpendicular in places, and towering to a height of 600 feet above the plain, is a very marked feature of the landscape, and at once suggests a very recent fault-scarp, while the fact that rhyolites and Permo-Carboniferous conglomerate are found along the top of the range on its western side,

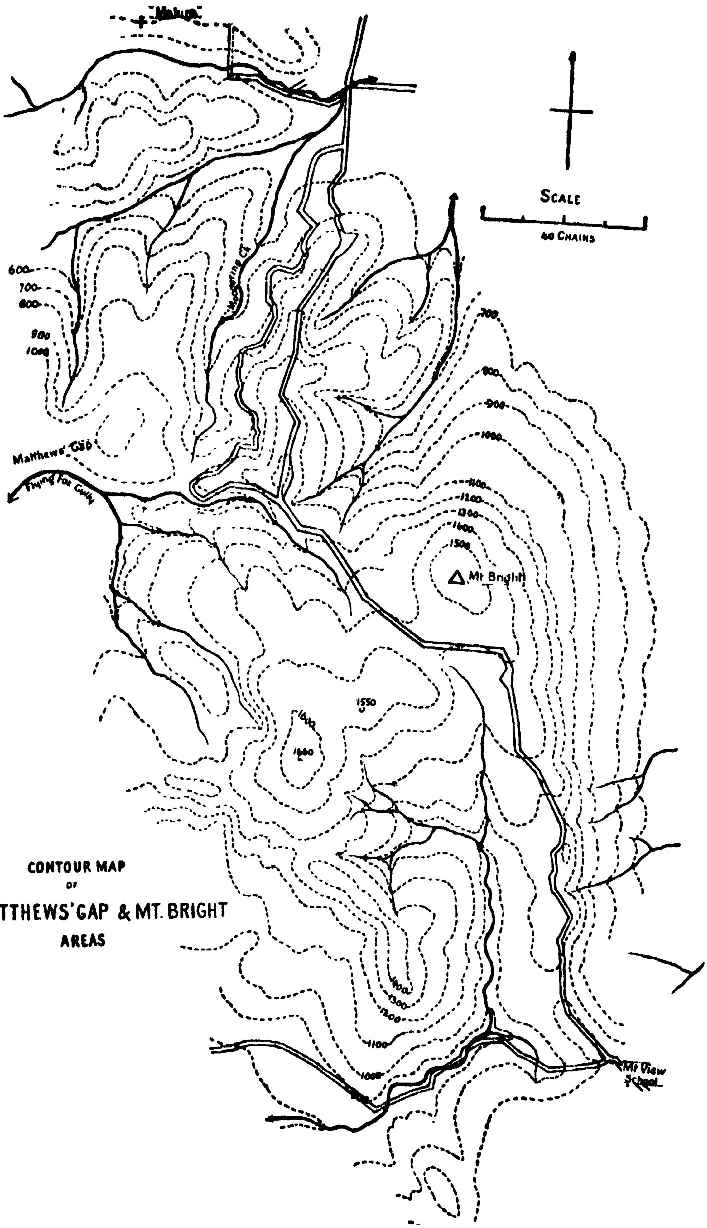



Fig 1.—*Contour Map of Matthews' Gap and Mount Bright Areas.*

and at the plain level on the eastern side, is undoubted evidence of local vertical movement. This fault, the more easterly of the two, is the older. Two other small and doubtful faults are shown on the map, at Post Office Hill, and at the place named Jerusalem Rock. In both cases the throw is probably small and the evidence for the faulting is mainly physiographic, showing that such faults, if they really exist, are of comparatively recent origin.

Other faults, postulated on geological grounds and noted on the map, will be referred to as they occur, in dealing with the general geology of the district.

### Geological Age of the Formations.

In this district there are representatives of two, and possibly three, geological periods. The principal and most interesting series, comprising acid, intermediate and basic lavas, is of Carboniferous age: in the Lower Marine of the Permo-Carboniferous, basic lavas and tuffs are developed: while underlying the Carboniferous lavas of Mount Bright is a long narrow outcrop of grano-diorite which is either Lower Carboniferous or Pre-Carboniferous. It is with the Carboniferous lavas that we are chiefly concerned in this paper.

Round the gently sloping elevations comprised in the Drake's Hill area the basal conglomerates and sandstones of the Lower Marine can be traced in such a way as to leave no doubt that they actually surround it. They appear dipping at a low angle off the igneous rocks, so that it may be concluded that Drake's Hill was an isolated elevation on the floor of the Permo-Carboniferous sea, against the sides of which these sediments were deposited. This conglomerate contains pebbles of the rocks of which the inlier itself is composed, so that the eruptives are anterior in age to the Permo-Carboniferous. The age of the Matthews'

Gap rocks has been determined on similar evidence, and by the fact that a tuff bed has been found containing Carboniferous fossils.

. A very definite and persistent horizon of Lower Marine conglomerate can be traced in many places from "Maluna" homestead as far as Mount View; this forms a very convenient datum bed, as it immediately overlies the Carboniferous rocks. The conglomerate is unfossiliferous and, apart from local inclusions of the underlying rocks, is characterised by very much rounded pebbles of quartz-porphyry and quartzites from some unknown locality. The conglomerate can be traced on both the eastern and western sides of the Mount Bright area. At one point on the western side, about one and a-half miles north of Mount View School, a beautiful section shows the sequence from the Carboniferous rhyolite through Carboniferous conglomerate, shales and grits to Permo-Carboniferous conglomerate and sandstone. At this point the latter are at least 200 feet thick, the unconformity between them and the Carboniferous being very slight.

That the Mount Bright grano-diorite is considerably older than the Carboniferous rhyolites has been definitely proved by the finding of pebbles of grano-diorite in the rhyolite and tuffs at different points along the junction of the two rocks. Since considerable denudation must have been necessary to lay bare the plutonic rock before the rhyolite flowed over it, the grano-diorite must be referred to the Lower Carboniferous or some anterior period.

## Geology of the Three Areas.

### A—Carboniferous Rocks.

*The Drake's Hill Area.*—The rocks consist mainly of rhyolite, rhyolite breccias and tuff, trachyte, and a number of isolated patches of andesite. The rhyolitic rocks are

mostly on and around the Post Office Hill, and have undergone very violent and extensive contortion, apparently when in a plastic condition and also subsequent to consolidation. The rhyolite is as a rule strongly banded, and the even course of the banding is often broken by folds varying from a fraction of an inch to several feet across. Persistent tilting of the rock mass is observed, the flows dipping at various angles in an average direction of about N. 10° E. The beds are cut off abruptly by the small submeridional fault already referred to, which also at its southern end throws down the trachyte against the rhyolite.

The rhyolite is mainly of the glassy type, no porphyritic quartz crystals being seen as is the case with the Mount Bright rock. What appears to be secondary material of a jasperoid nature, dark brown to black in colour, is of frequent occurrence. There is evidence of several successive flows in this area, the earlier of which were brecciated by the later eruptions. Fine rhyolite tuff also occurs in considerable abundance, and a hard green tuff which is sparingly found seems to be a modification of the rhyolite tuffs. Trachyte overlies and partly surrounds the rhyolite. It is in places of a tuffaceous nature, and is of the leucocratic or acid type, light brown in colour. The andesite probably represents the remnants of former flows on top of the trachyte or intrusive into it.

An outcrop of chocolate shales and dark coloured conglomerate is exposed in the bed of a creek on the Rothbury Road, not far from the Post Office. These are entirely different in appearance and constitution from the known Permo-Carboniferous rocks, for which reason they have been put down as Carboniferous and correlated with similar occurrences in the other areas.

*Mount Bright Area.*—Here a very much older formation is met with in the shape of grano-diorite; as its age may

be Carboniferous, it may be conveniently be treated here. It outcrops in a long narrow band along the eastern face of the range between Mount Bright and Mount View. The typical rock is medium-grained, with a slight preponderance of light over dark coloured minerals. At the northern limit of the occurrence two extremely well marked types of local differentiation products occur, the first being a basic modification, much darker in appearance than the general type. From examination of hand-specimens the ferro-magnesian constituents hornblende and biotite are seen to predominate, forming about 80 per cent. of the rock, while the remainder consists of plagioclase, pink orthoclase and a little quartz. A short distance away a further modification appears in the shape of a pink aplite, consisting of porphyritic laths of plagioclase, showing albite and carlsbad twinning, in a fine-grained base of quartz and felspar with subordinate biotite. Pyrites in very small crystals is abundantly distributed. The aplite in places also contains irregular small patches of tourmaline, and large segregations of the same mineral showing fibrous radial structure also occur, probably as a result of pneumatolytic action. The final phase of differentiation of the grano-diorite magma is represented by a pegmatite. This rock is extremely coarse in texture and consists of an intimate intergrowth of allotriomorphic to subidiomorphic quartz and pink felspar. At this northern end the grano-diorite is cupriferous, the copper minerals being in close association with the pegmatite. Azurite, malachite, peacock ore, pyrites, etc., have been obtained near the upper boundary of the grano-diorite, but the workings are now abandoned. Attempts to find copper near the Mount View end of the outcrop have proved unsuccessful.

Rhyolite and rhyolite tuffs are the earliest of the Upper Carboniferous volcanic series, and form the greatest part

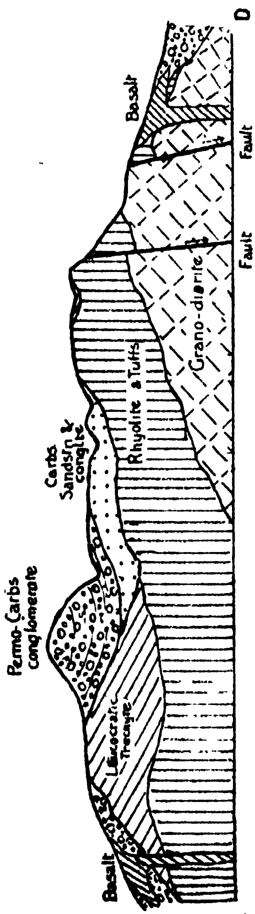
of the rocks of this area. The rhyolite here does not appear to have suffered so severely from earth movements as that of Drake's Hill, and in appearance differs from it in many respects. Typically the Mount Bright rock is whitish to dark red in colour, sometimes, but not invariably, strongly banded and containing small idiomorphic quartz and felspar crystals sparsely distributed. Secondary chalcedony is found, opaque yellowish to red in colour.

On the edges of the area a coarse agglomerate is developed, containing boulders of banded rhyolite up to about a foot in diameter. This may have been produced towards the close of the rhyolite eruptions or may represent the result of the first explosive outbursts of trachytic lava. Overlying the rhyolite, and filling in eroded hollows in it, are flows of trachyte of considerable extent, generally yellowish-brown in colour and containing small laths of felspar in an aphanitic base. The relations of this trachyte to the rhyolite are very definite.

Only three very small occurrences of basic rocks have been observed among the Carboniferous eruptives, in the shape of what appear to be small necks of basalt and dolerite. The mineralogical and structural points of similarity connecting these occurrences suggest that they should be correlated, but as the occurrences are isolated from other basic rocks their precise geological age is difficult to determine; all that can be said is that they are post-trachyte.

Resting directly upon the acid lavas and underneath the Permo-Carboniferous conglomerate is a Carboniferous sedimentary series, consisting of conglomerates, fine grained friable chocolate shales and tuffaceous sandstones: some or all of the members of this series can be traced at many points around the area, and up into the Matthews' Gap area. They are well seen on the road about half a mile

N.W. of Mount View School, where the whole sequence from the rhyolite to Lower Marine conglomerates can be traced, the Carboniferous sediments dipping at about 12° off the rhyolite and attaining a thickness of 400 feet. On the western side the formation appears as tuffaceous sandstones, in close association with rhyolite agglomerate, and containing obscure plant remains. On the eastern side the greater part of the sediments has been faulted out of sight, save in a few places where small outcrops of chocolate shales are seen.




Section

The exposure of the grano-diorite in this area is probably the effect of the older Mount Bright fault. A glance at the maps and at Section 1 will serve to explain how the faulting has brought down the rhyolite to a much lower level and thrown it against the grano-diorite, at the same time exposing the latter.

*Matthews' Gap Area.*—While this area is continuous with the others in respect of the more acid lavas, the occurrence of more basic rocks is better marked as regards both extent and variety. The rhyolite tuffs appear as isolated outcrops mostly confined to the northern end, but nearer Matthews' Gap itself the rhyolites are completely hidden under trachytes, basalt, agglomerate, trachy-

andesite, and dacite, with patches of Permo-Carboniferous quartz-porphyry conglomerate dipping off the eruptives or filling in old valleys. The tuffs or breccias are of a somewhat different variety from those occurring at Drake's Hill and Mount Bright. They are medium in texture, the fragments being up to about two inches long, and ranging down to microscopic dimensions. The inclusions comprise fragments of cherty rock, rhyolite of various colours, trachyte of a kind not met with in the flows of the district and therefore probably of much earlier date, and fine-grained green siliceous-looking rock probably closely related to the green tuff of Drake's Hill and to another tuff found elsewhere in the Matthews' Gap area. The latter seems to be a variety of the rhyolite tuff. It is extremely fine-grained, of a blue-green colour, hard and compact. Its chief difference from the Drake's Hill green tuff consists in the presence of abundant felspars, largely idiomorphic, but often with the appearance of angular fragments, suggesting that they are of extraneous origin—not crystallised in the tuff.

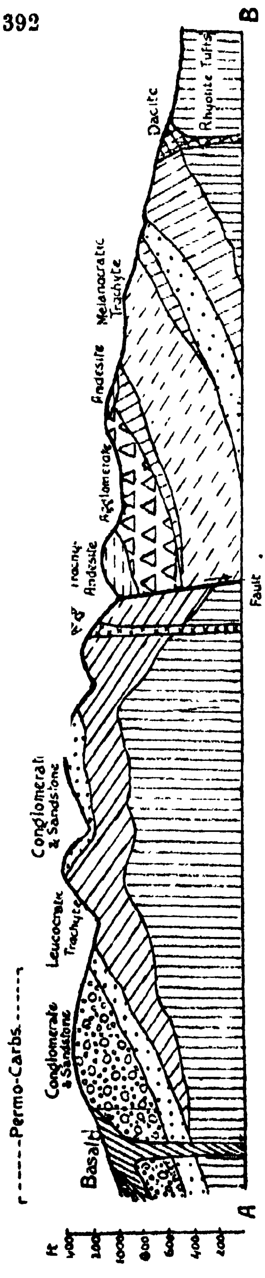
Some other very fine grained tuffs are found occurring on top of the coarser rhyolite tuffs, in particular that already referred to as containing the Carboniferous plant fossils *Rhacopteris* and *Cardiopteris*, also an extremely fine-grained greenish-white cherty tuff which is to be found on the N.W. end of Mount Bright. Both of these are stratified, and the Rhacopteris tuff is in places fractured and shattered; the pieces having slipped on each other, excellent miniature examples of different kinds of faulting have been produced.

Trachyte is very abundant, and has followed directly on the rhyolite and tuffs. It may be divided into two varieties, leucocratic and melanocratic, this division being based on a microscopic comparison of the two types. It is more fully discussed below. The leucocratic trachyte is of a

brownish colour, similar to that in other parts of the district, with small phenocrysts of felspar showing macroscopically. The melanocratic variety is much finer and more even grained, and is of a bluish colour, having the general appearance of a rather light-coloured basalt. The leucocratic type has the wider distribution, and is the older of the two types: on top of it the Carboniferous sedimentary rocks, represented by sandstones and conglomerates, have been deposited. On top of the conglomerate are further flows of trachyte, both the leucocratic and melanocratic varieties, accompanied by dykes and sills in the conglomerate. More basic rocks succeed, the most extensive and important being a coarse agglomerate associated with basic looking tuffs, which are capped by trachy-andesite and andesite. The blocks in the agglomerate are often rounded, giving the appearance of a coarse conglomerate; they include rocks of a felsitic nature, with pebbles of a green tuffaceous-looking rock, and the cementing material is of a dark basic appearance, but of undetermined composition. The whole of this series is well exhibited on the long ridge along which run the old and new roads to Matthews' Gap.

Probably connected with the same outbursts is the intermediate glassy rock or pitchstone, of which a couple of isolated outcrops are found and of which an analysis is given below, and the andesite in the N.W. portion of the area. The most basic portions of the Matthews' Gap area series are a flow of basalt and associated tuffs.

The last phase of the volcanic activity of Carboniferous age is represented by a flow of dacite, which partially conceals the outcrop of many of the earlier rocks, and which is immediately under the Permo-Carboniferous conglomerate in some places. Dykes of leucocratic trachyte in the agglomerate and trachy-andesite may belong to the same phase.



Section 2

The western extension of the agglomerate outcrop is cut off under this dacite, but on the eastern side it abruptly joins the Mount Bright trachyte, and is seen no further south. A similar sharp boundary exists for the trachy-andesite and Mount Bright trachyte, and these circumstances indicate a faulted junction. (Vide Section 2.)

Another small fault is probably to be placed to the east of the old road, letting down the Carboniferous conglomerate and trachyte a vertical distance of about a hundred feet. No great extension of this fault can be traced, whence it may be argued that it antedated the agglomerate and consequently the dacite. A line of fracturing and crushing is developed in the dacite, whereby a typical crush-breccia has been produced. Every phase can be traced, from the unjointed rock, through a highly jointed zone to a zone of intense fracture and lateral movement. This is however, merely a local phenomenon.

A fault on the extreme west of the area which has brought

the Upper Marine sandstones into juxtaposition with the Carboniferous formations is probably part of the Eldersiee fault of Professor David which has caused the burying of the Greta coal measures to a considerable depth.

### B. Permo-Carboniferous Rocks.

These have not been studied in detail, but their relationships have been noted where they are contiguous with the Carboniferous rocks. The most notable among the sedimentary series is the quartz-porphyry conglomerate, which in this district appears to form the lowest of the Permo-Carboniferous strata. It has been suggested, however, that any possible lower beds have been concealed through overlapping. The conglomerate sometimes disappears and then the eruptives are immediately overlain by the Lower Marine sandstones.

The igneous rocks are confined to basalt and tuffs contemporaneous in the Lower Marine. The position of these is indicated in the geological map, and it will be observed that in the southern portion of the district they exist as a marginal belt to the Carboniferous rocks. They occur some distance up in the Lower Marine, intrusive through the basal conglomerate and some of the overlying sandstone. Their contemporaneity is proved by the presence of *Stenopora* and *Fenestella* found by Professor David in the associated tuffs on the western side of the Mount Bright area.

A considerable extent of the basalt on this western side is amygdaloidal, the steam holes being filled with zeolites, chiefly radiating aggregates of natrolite, often in fairly large masses, with associated minor development of pinkish datolite and analcite. It is a remarkable circumstance that similar occurrences are not met with in the basalt on the south and east of the area.

The country between the Drake's Hill volcanics and "Maluna" is composed principally of Lower Marine sediments—conglomerate, sandstone and foraminiferal limestone. A belt of basaltic or andesitic lava can be imperfectly traced by means of the resulting soil and by a few obscure and decomposed outcrops, but this has not been accurately mapped, as the boundaries are impossible of delimitation.

North of the Drake's Hill area, in the Parish of Rothbury, is a small low conical hill composed of basalt, with a few short dykes radiating from it. The relations of this outcrop are much obscured by recent alluvium, but it is in all probability contemporaneous in the Lower Marine. It is surrounded by Lower Marine sandstones which a short distance away are distinctly dipping towards the outcrop.

**Order of Succession of the Lavas.**

As a result of our investigations we are inclined to advance the following order of succession for the rocks of the district :—

Carboniferous :

i. Rhyolite and rhyolite tuffs.
ii. Trachyte, beginning with leucocratic, and followed by melanocratic.
iii. Agglomerate, trachy-andesite and andesite.
iv. Dolerite and olivine basalt necks, and basalt flows.
v. Dacite and (?) dykes of trachyte.

Permo-Carboniferous :

vi. Basalt.

The positions of the rocks under iv, and of the trachyte dykes are of course not certain, but there is little doubt that the general character of the succession is correct. There seem to have been several eruptions of rhyolite, both as quiet flows and as explosive outbursts. The trachyte

followed on the rhyolite apparently without any considerable interval. Succeeding the trachyte was a period of quiescence in the vulcanicity and of gradual subsidence, during which the Carboniferous conglomerates, shales and sandstones were laid down, before volcanic action recommenced. The longest period of volcanic inactivity was probably that between the dacite and the Lower Marine basalt. During this interval the Permo-Carboniferous sedimentation began and advanced to a considerable degree.

### Petrology.

The rocks found in the district include, as has been already shown, a wide range of types. They may be divided up as follows:—

A. Plutonic,

B. Hypabyssal, and

C. Volcanic (i) acid
(ii) intermediate, and
iii) basic.

The only plutonic representative is the grano-diorite mass exposed along the eastern face of Mount Bright. Hypabyssal rocks are represented by the dolerite at Matthews' Gap which occurs as a (?) volcanic neck, and the small neck of ophitic dolerite in the Mount Bright area. The acid volcanics include the rhyolites and the dacite, both occurring as flows, and probably the leucocratic trachytes can be classed with these. The intermediate volcanics include the melanocratic trachyte (which in hand-specimens resembles very closely a light coloured-basalt), trachyandesite, andesite and pitchstone. Among the basic rocks there are olivine basalt, and basalt.

One of the most noticeable features of the volcanic series is the extremely limited development of ferro-magnesian constituents. This is very marked in the trachytes and

andesites, which are almost devoid of such minerals. In some cases, however, a good deal of alteration has taken place, and it is possible that a good deal of the ferro-magnesian mineral has been replaced by secondary material. The norms of the two analyses of quite fresh rocks (andesite and pitchstone) calculated according to the American classification, show respectively 16·78 and 11·80 per cent. of pyroxene; from this it seems probable that there is a good deal of ferro-magnesian constituent present in the base though it cannot readily be distinguished under the microscope.

### A. *Plutonic.*

#### Grano-diorite.

Coarse-grained phanerocrystalline rock, consisting of quartz, felspar, hornblende and biotite as far as can be seen in hand specimen. Quartz and felspar form more than half the rock. Under the microscope the rock is holo-crystalline. Its grainsize is even and coarse, and the grains have an average diameter of about 2 mm. The fabric is hypidiomorphic granular.

The minerals present are:—Plagioclase, orthoclase, quartz, biotite, hornblende, magnetite, apatite and sphene.

Plagioclase is the most abundant mineral; it is subidiomorphic and is twinned after the albite law. It is a good deal decomposed. The orthoclase is not so abundant but is present in fair quantity. Both the felspars are crowded with inclusions of tiny fragments of biotite, hornblende and magnetite. Quartz is present but not abundantly. The biotite is slightly decomposing to chlorite in places, and has a rather fibrous appearance. The hornblende is the green variety and is decomposing to chlorite. Apatite and magnetite are fairly abundant and sphene is sparingly present. The order of consolidation is:—

Apatite
Magnetite
Sphene
Hornblende
Biotite
Plagioclase
Orthoclase
Quartz

B. *Hypabyssal.*

Dolerite, Matthews' Gap.

A greenish coloured greasy-looking rock; phanerocrystalline and fine-grained. Felspar and a dark ferro-magnesian mineral can be seen in hand specimen. Porphyritic crystals of pyroxene showing hour-glass structure are also visible. Under the microscope it is holocrystalline with a few porphyritic crystals. The base has medium grainsize. The fabric is hypidiomorphic granular.

The minerals present are:—Plagioclase, augite, magnetite, chlorite and calcite.

The plagioclase is in tabular idiomorphic crystals, zoned and twinned after the albite, carlsbad and pericline laws. It is partly decomposed to kaolin, the decomposition often being zonal. A symmetrical section showing both albite and carlsbad twinning gives two symmetrical extinctions viz.:—$24\frac{1}{2}^\circ$ and $37\frac{1}{2}^\circ$, indicating that it is labradorite with composition $Ab_2An_3$. Augite is in large subidiomorphic crystals with zonally arranged inclusions. A good deal of chloritic material is present as decomposition product, probably from biotite. Magnetite is present in idiomorphic crystals. A little secondary calcite is also present.

C. *Volcanic*, (i.) acid.

Rhyolite.

The rhyolite varies a good deal from place to place. Typically in hand specimen it is light in colour, with small phenocrysts of clear glassy quartz and pink felspar in an aphanitic groundmass. Flow-structure is well developed in places, but is more often absent. Cavities in the rock are of frequent occurrence and are almost always filled with secondary material—this is generally chalcedony, agate or some other form of secondary silica. Such secondary material is plentiful in the Mount Bright area, but is of less frequent occurrence at Drake's Hill. At Drake's Hill, however, the rhyolite has been brecciated and very numerous cracks, transverse to the lines of flow as well as parallel to it, have been filled with a deposit of black jasperoid material.

Under the microscope it is markedly banded, and has a cryptocrystalline to microcrystalline base with few phenocrysts. The phenocrysts are felspar and quartz; the felspar is idiomorphic and somewhat decomposed. Drusy cavities are present and are generally filled with fine quartz grains and in places microscopic quartz crystals can be seen projecting from the sides of the cavities. Minute cracks transverse to the direction of the banding are filled with quartz. At Drake's Hill there is a good example of brecciation of the rhyolite. The rock has been much crushed and crumpled; the original banding of the rhyolite is generally still visible, but the cracks have become filled with dark coloured secondary jasperoid material.

An analysis of rhyolite from half a mile south of Mount Bright by Mr. J. C. H. Mingaye,[1] is as follows:—

| | | | |
|---|---|---|---|
| $SiO_2$ | 77·82 | $H_2O$ | 1·40 |
| $TiO_2$ | 0·02 | $H_2O$ | 0·36 |
| $Al_2O_3$ | 11·46 | $CO_2$ | 0·03 |
| $Fe_2O_3$ | 0·30 | $P_2O$ | 0·04 |
| $FeO$ | 0·09 | $SO_3$ | 0·07 |
| $MnO$ | (< 0·01) | $BaO$ | 0·02 |
| $MgO$ | 0·23 | $Li_2C$ | trace |
| $CaO$ | 0·22 | | |
| $K_2O$ | 7·19 | | 100·11 |
| $Na_2O$ | 0·86 | | |
| | | Sp. gr. | 2·596 |

[1] Kindly furnished by the Department of Mines.

Rhyolite Tuffs.

These occur abundantly throughout the whole district. They are generally light in colour and are very solid. Their texture varies from very fine to very coarse. In the coarser ones angular fragments varying from half an inch to several inches in diameter are cemented together by extremely fine grained siliceous material; the very fine ones on the other hand are composed completely of crypto-crystalline to microcrystalline siliceous material, with a small amount of felspathic material and glass. The base in places shows obscure traces of lamination and contains fragments of felspar crystals and quartz. Occasionally large quartz grains are corroded and much granulated.

Dacite, Matthews' Gap Road.

These rocks vary in colour from a light brown to dark reddish-brown. The lighter coloured varieties appear to be slightly more acid than the darker ones. They are porphyritic in texture with aphanitic ground mass. The phenocrysts in the lighter coloured ones are chiefly quartz and felspar; biotite is only sparingly present. In the darker ones quartz and felspar are abundant, as is also biotite, the latter being well developed in hexagonal plates. In places they are somewhat tuffaceous.

Under the microscope they are all hypocrystalline, with porphyritic texture. The phenocrysts vary in size from medium to large. The base is generally made up of brown glass, but occasionally it is partly cryptocrystalline; the fabric of the ground mass is fluidal. Plagioclase and quartz form the bulk of the phenocrysts; plagioclase is the more abundant of the two. The quartz is in corroded subidiomorphic to idiomorphic grains. It contains inclusions of the ground mass and shows very little evidence of strain. Plagioclase is abundant, but rather decomposed.

It shows albite twinning and sections in zone perpendicular to (010) give symmetrical extinctions up to 21° showing that it is a labradorite of composition about $Ab_4An_8$. It shows a variety of decomposition products—some of it is decomposed to kaolin, some shows a development of sericitic aggregates along twinning planes, and still other pieces are almost completely pseudomorphed by calcite; in the latter case there is considerable development of hematite along the cleavage and twinning planes. Biotite is present as small long ragged flakes, some of which are considerably bent. Magnetite and apatite are also present and there is a small amount of chlorite.

Dacite (dyke rock) New Matthews' Gap Road.

This is a dyke related to the dacite. It is porphyritic with a glassy base and showing well marked flow-structure. The phenocrysts are generally coarse, with an average diameter of 2 to 3 mm. They consist chiefly of quartz and felspar. The quartz is in some cases beautifully corroded and contains inclusions of the ground mass. The felspars are much decomposed and there is a heavy deposit of hematite along the cleavage and twinning planes. Flakes of biotite are present and also ilmenite.

Trachyte, Drake's Hill.

This is a brown, fine-grained rock. It is slightly drusy and secondary minerals are developed in the druses. Crystals of a pinkish-coloured felspar can be recognised in hand specimen. Under the microscope it is hypocrystalline and porphyritic. The phenocrysts' average size is medium. There are two generations of felspar. Those of the larger generation are medium-sized subidiomorphic crystals. They consist of both orthoclase and plagioclase, the former being the more abundant. The plagioclase is twinned after the albite law. The smaller ones consist of very fine needles

scattered throughout the base. The larger ones are considerably dusted with kaolin. Patches of the rock are stained with iron oxide. Magnetite is the only other mineral visible.

Trachyte, top of Matthews' Gap Road.

Light brown coloured, vesicular rock. The steam holes are flattened and have their longer axes all lying in one direction. Pink crystals of felspar can be seen in hand specimen, making the rock slightly porphyritic. The base is fine-grained, aphanitic. Under the microscope the rock is hemicrystalline, hypocrystalline, slightly porphyritic and with a slightly fluidal fabric. The minerals are:—Orthoclase, plagioclase, quartz, and magnetite, and a small amount of glass is present. The orthoclase is most abundant and is also considerably decomposed. There is a second generation of felspar in the form of minute microlites in the base. Quartz is present in somewhat rounded grains. Magnetite is not abundant. The base consists mostly of a brownish-coloured glass.

C. *Volcanic*, (ii) intermediate.

Melanocratic trachyte, New Matthews' Gap Road.

Bluish-black in colour and very solid. Fracture subconchoidal; fine-grained, aphanitic. Very small felspars can be recognised in hand specimen, and the rock resembles a light-coloured basalt. Under the microscope it is hypocrystalline; the fabric is trachytic and somewhat fluidal. Both orthoclase and plagioclase are present, the former being the more abundant. It is in rather decomposed tabular crystals. The plagioclase is an acid labradorite. There are two generations of the felspar, the larger ones averaging about ·75 by ·25 mm., and the smaller ones are only fine needles. Magnetite is abundant in small grains. There is a very dark mineral present in small grains which

are slightly pleochroic but too small to be accurately determined—they are probably pyroxenes. The base forms about 20 per cent. of the rock and contains a moderate proportion of light-coloured glass.

Trachy-andesite, Matthews' Gap Road.

Fine-grained rock, appearing rather tuffaceous in parts. A pink secondary mineral is present. Under the microscope it is hypocrystalline and slightly porphyritic; the fabric is trachytic. The phenocrysts are of felspar and magnetite; the felspar is in idiomorphic tabular crystals, somewhat decomposed, and is mostly orthoclase. The base is composed of minute felspar microlites and numerous small magnetite grains. There are a few grains of pale green mineral with low D.R., probably chlorite.

Andesite, Old Road.

Dark blue rock, slightly porphyritic with fine-grained base. Very hard and fresh and weathers into spheroidal lumps. Minerals visible in hand specimen are lath-shaped glassy felspars and a small amount of dark ferro-magnesian mineral. Under the microscope the texture is porphyritic. The phenocrysts average about 1 by 1·5 mm., the base is hypocrystalline. Plagioclase constitutes the great majority of the phenocrysts and a section parallel to (010) gives an extinction of $-20^\circ$ measured from the cleavage parallel to (001) and the plagioclase is therefore labradorite ($Ab_3An_4$). There are a few large grains of magnetite. The base is made up of small lath-shaped felspars, very numerous grains of magetite, minute apatite prisms, small dark grains, almost opaque, too small to identify but probably pyroxene, and a fair amount of light coloured-glass. This has been analysed, with the following result :—

| | Per cent. | Molec. propor. | | Per cent. |
|---|---|---|---|---|
| $SiO_2$ | 55·20 | 920 | Quartz ... | 4·98 |
| $TiO_2$ | 1·17 | 15 | Orthoclase ... | 5·56 |
| $Al_2O_3$ | 20·14 | 197 | Albite ... | 40·34 |
| $Fe_2O_3$ | 3·55 | 22 | Anorthite ... | 30·58 |
| FeO | 3·46 | 48 | Diopside .. | 9·27 |
| MnO | 0·09 | 2 | Wollastonite | 1·51 |
| MgO | 1·10 | 28 | Magnetite ... | 5·10 |
| CaO | 9·17 | 164 | Ilmenite ... | 2·28 |
| $K_2O$ | 0·96 | 10 | Water .. | 1·36 |
| $Na_2O$ | 4·80 | 77 | | 100·98 |
| $H_2O$ + | 1·25 | | | |
| $H_2O$ − | 0·10 | | | |
| $CO_2$ | absent | | | |
| $P_2O_5$ | trace | | | |
| | 100·99 | | | |

$$\frac{\text{Sal}}{\text{Fem}} = \frac{81·46}{18·16} < \frac{7}{1} > \frac{5}{3}$$

Class ii (Dosalane)

$$\frac{Q}{F} = \frac{4·98}{76·48} < \frac{1}{7}$$

Order 5 (Germanare)

$$\frac{K_2O+Na_2O}{CaO} = \frac{87}{164} < \frac{3}{5} > \frac{1}{7}$$

Rang 4 (Hessase)

$$\frac{K_2O}{Na_2O} = \frac{10}{77} < \frac{1}{7}$$

Subrang 4

## Andesite, Drake's Hill.

Dark-coloured fine-grained rock. Well-developed flow-structure shown by the parallel orientation of slightly porphyritic felspar crystals. Very small amount of ferro-magnesian mineral visible in hand specimen. Considerable amount of variation from place to place, the chief points of variation being the size of the felspars, the amount of ferro-magnesian constituent and the degree of development of flow-structure.

Under the microscope it is hypocrystalline and porphyritic. The base is mostly glassy. Felspar is present in two generations; the larger are idiomorphic and twinned after the albite law; a number of symmetrical sections gave a maximum extinction angle of 26° so the felspar is labradorite ($Ab_1An_1$). The smaller ones are fine needles and they accentuate the flow-structure. There is a good deal of magnetite present. Very little ferro-magnesian mineral is present, but a certain amount of pale green chlorite is developed, and this seems to be probably from the alteration of ferro-magnesian minerals. In one example there is a small amount of decomposed biotite present.

## Pitchstone, Portion 42, Parish Pokolbin.

In hand specimen a black vitreous rock, almost completely glassy, a few small crystals of felspar being visible.

Under the microscope the rock is hypohyaline; the base is mostly of glassy material and contains a large number of extremely small felspar microlites. The glassy material is dark in colour, probably on account of the fairly large amount of magnetite distributed in very minute grains. The small microlites exhibit a parallel arrangement, bringing out the flow structure present. There is also a larger generation of felspars having a size of about 1 mm. by ·5 mm. It is twinned after the albite law and is labradorite. There are a few small grains of another mineral almost colourless, with only very slight pleochroism. Its D.R. is negative and approx. ·010 and the R.I. is considerably higher than that of Canada balsam. It has parallel extinction and is biaxial. There seems to be no doubt that it is hypersthene. Magnetite is the only other mineral visible. This rock has been analysed with the following result:—

| | Per cent. | Molec. propor. | | Per cent. |
|---|---|---|---|---|
| $SiO_2$ | 58·79 | 980 | Quartz ... | 11·46 |
| $TiO_2$ | 1·21 | 15 | Orthoclase | 3·89 |
| $Al_2O_3$ | 17·51 | 172 | Albite ... | 40·87 |
| $Fe_2O_3$ | 2·11 | 13 | Anorthite .. | 24·18 |
| FeO | 3·87 | 54 | Diopside ... | 5·29 |
| MgO | 2·23 | 56 | Hypersthene | 6·51 |
| CaO | 6·18 | 110 | Magnetite .. | 3·02 |
| $K_2O$ | 0·68 | 7 | Ilmenite ... | 2·28 |
| $Na_2O$ | 4·84 | 78 | Water ... | 3·32 |
| $H_2O$ + | 2·61 | | | 100·82 |
| $H_2O$ - | 0·71 | | | |
| $CO_2$ | trace | | | |
| | 100·74 | | | |

$$\frac{\text{Sal}}{\text{Fem}} \quad \frac{80 \cdot 40}{17 \cdot 10} > \frac{5}{3}$$

Class ii (Dosalane)

$$\frac{Q}{F} = \frac{11 \cdot 46}{68 \cdot 94} < \frac{3}{5} > \frac{1}{7}$$

Order 4 (Austrare)

$$\frac{K_2O + Na_2O}{CaO} = \frac{85}{110} < \frac{5}{3} > \frac{3}{5}$$

Rang 3 (Tonalose)

$$\frac{K_2O}{Na_2O} = \frac{7}{78} < \frac{1}{7}$$

Subrang 5 (Placerose)

C. *Volcanic*, (iii) basic.

Basalt, west of Moogering Creek.

Dark aphanitic rock with uneven fracture. Tiny lath-shaped felspars can be recognised in hand specimen.

Under the microscope it is hypocrystalline, pilotaxitic. A small amount of interstitial glass is present in the base. Felspar is present in lath-shaped crystals with their longer axes in a generally parallel direction. Magnetite is abun-

dant in small grains. A light-coloured ferro-magnesian mineral is present in small grains, probably augite. Chlorite is sparingly present. A good deal of secondary calcite is present.

Olivine basalt, Portion 78, Parish Milfield.

Dark, rather heavy rock. Felspar and a dark mineral can be seen in hand specimen. Microscopically it is hypocrystalline, the amount of glass being very small. Radiate fabric is fairly well developed and ophitic structure is present. The minerals are:—Plagioclase, olivine, augite, magnetite and serpentine. The plagioclase is quite fresh in idiomorphic lath-shaped crystals whose maximum extinctions in sections perpendicular to (010) is 39°, indicating a bytownite of composition near $Ab_3An_7$. The augite is titaniferous, violet in colour and with fairly marked pleochroism. It is abundant, but only in small pieces, and ophitically encloses plagioclase. Olivine is present in fair quantity and is partly altered to serpentine, the alteration having taken place round the periphery and along the numerous cross cracks present. Magnetite is present in numerous small grains mostly included in other minerals.

Basalt, Portion 55, Parish Milfield.

Under the microscope it is hypocrystalline. The fabric is somewhat fluidal. The minerals are:—Plagioclase, augite, biotite, magnetite and a pale green zeolite. The plagioclase is in lath-shaped crystals and a good deal decomposed to kaolin. The augite is titaniferous and slightly pleochroic. Biotite is dark reddish-brown in colour, idiomorphic, often in hexagonal sections, with parallel extinction and pleochroic. Sometimes the central part is altered to a greenish aggregate. There is also a fairly large amount of pale green zeolitic mineral present.

Rhacopteris tuff, Matthews' Gap Road.

Fine grained, very compact and laminated. It has a bluish-grey colour when freshly fractured, but after short exposure (a few weeks) to atmospheric weathering it becomes brown. It has evidently undergone considerable local movement, as seen from the large number of perfect miniature faults which are present. It contains scanty remains of *Rhacopteris* and *Cardiopteris.*

Under the microscope it consists of rounded and angular fragments of felspar and quartz, mostly very much iron stained, cemented together by light-coloured glassy material. A good deal of calcite is present.

Cherty tuff, North of Mount Bright.

Light-coloured greyish-green, fine-grained rock; laminated and considerably jointed. Under the microscope it is extremely fine-grained and is composed of minute grains of quartz, and felspar and small amounts of magnetite and probably rutile and pyroxene, with a cementing material which appears felspathic.

**Summary.**

In the foregoing remarks we have endeavoured to establish the following main points:—

i. Partly underlain by earlier plutonic rocks, a complex of Upper Carboniferous volcanic lavas exists in the Pokolbin District constituting a series of inliers in the Permo-Carboniferous sediments, the formation being substantially continuous from a point about half a mile north of Drake's Hill to the outcrop known as Jerusalem Rock.

ii. A series of basaltic rocks occurs contemporaneous in the Lower Marine of the Permo-Carboniferous.

iii. The two series of rocks together form a succession showing a gradual order of differentiation from rhyolite to

basalt, with a second phase of three components, dacite and trachyte, followed by basalt.

iv. The rocks have been much faulted, the period of disturbance ranging from (?) Carboniferous possibly to Tertiary times.

It is suggested that the lava extrusions were in the nature of fissure eruptions, the axes of extrusion being roughly meridional, and that this accounts for local modifications in the rock types. A petrological description of the typical rocks has been given.

### Conclusion.

Our first geological acquaintance with Pokolbin was made at a University camp four years ago under the leadership of Professor David, and we wish to acknowledge our indebtedness to him for kind permission to make use of his maps of the district, for advice as to the general trend of our work and for his kindly and encouraging interest. Our sincere thanks are also due to Mr. W. Eustace Wilkinson of "Maluna," Pokolbin, who at all times generously placed at our disposal his extensive and practical knowledge of the geology of the district. The good people of the district in which our field work lay we always found ready and willing to assist us by any means in their power, a circumstance which often lightened our labours and added to the pleasure with which we pursued our investigations.

### Explanation of Plates.

Plate XXV., Geological Map of the eruptive and associated rocks of Pokolbin, New South Wales.

Plate XXVI., Fig. 1. Banded rhyolite, from Post Office Hill, showing contortion ( $\times \frac{2}{3}$).

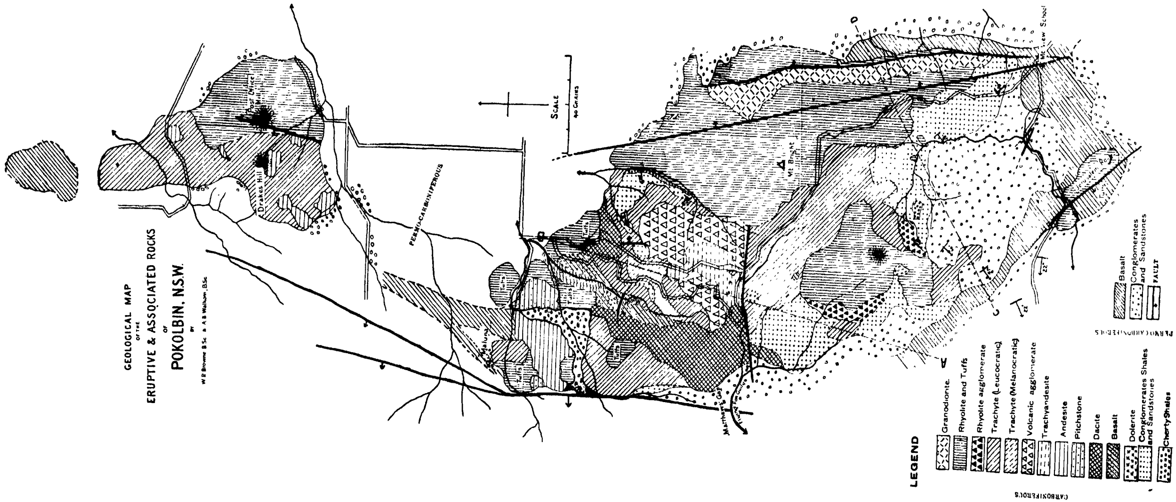
" " 2. Brecciated rhyolite, Post Office Hill ( $\times \frac{3}{4}$).

Plate XXVII., Fig. 3. Rhacopteris tuff, showing miniature faulting ( $\times \frac{3}{4}$).

Plate XXVIII. „ 4. View of Drake's Hill and Post Office Hill from New Matthews' Gap Road.

„ „ 5. View looking towards Mount Bright from "Maluna."

Plates XXVI and XXVII from polished specimens kindly lent by Mr. W. Eustace Wilkinson.


GEOLOGICAL MAP
OF THE
ERUPTIVE & ASSOCIATED ROCKS
OF
POKOLBIN, N.S.W.
BY
W. R. Browne B.Sc. & A. B. Walkom, B.Sc.
SCALE
40 Chains
PERMOCARBONIFEROUS
Post Office
Drakes Hill
Mt. Bright
Marthew's Gap
Tuffs
LEGEND
Granodiorite.
Rhyolite and Tuffs
Rhyolite agglomerate
Trachyte (Leucocratic)
Trachyte (Melanocratic)
Volcanic agglomerate
Trachyandesite
Andesite
Pitchstone
Dacite
Basalt
Dolerite
Conglomerates Shales and Sandstones
Cherty Shales
CARBONIFEROUS
Basalt
Conglomerates and Sandstones
FAULT
PERMOCARBONIFEROUS

Fig

# NOTE ON THE LIMITATIONS OF DE CHAULNES METHOD OF DETERMINING REFRACTIVE INDEX.

*By LEO. A. COTTON, B.A., B.Sc., Linnean Macleay Fellow in Geology.*

THIS note was prepared about three years ago at the suggestion of Dr. W. G. Woolnough, whom I wish to thank here for his encouragement in its preparation.

## DE CHAULNES' METHOD FOR DETERMINING REFRACTIVE INDEX.

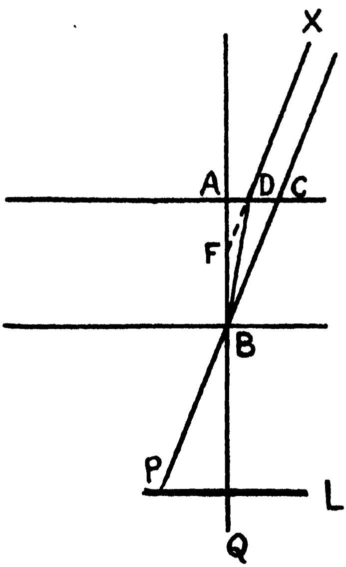



FIG. 2.

If light be converged by a lens L and passed through a glass slip or mineral section with parallel faces, each ray is refracted. Suppose the converged light after passing through the slip AB to be received into a microscope which has QB the normal to the plane faces of the slip as its line of collimation.

Let PBQ be the angle that the converged light makes with the normal to the plane faces of the slip.

On entering the slip the ray will be deflected along some direction BD such that sin. PBQ : sin. ABD $= \mu$ : I where $\mu$ is the refractive index of the substance of which the slip is made.

On emerging from the slip the light is again refracted and passes along a path DX which is parallel to its former direction PB.

If an object lies at B, then the introduction of the slip causes it to appear at F.

If the microscope was focussed on the object at B before the introduction of the slip, then in order that the object may be in focus after the introduction of the slip it will be found necessary to raise the objective through a distance FB.

The refractive index of the slip can be expressed in terms of the distance BF and the thickness of the mineral section as follows :—
Let BF$=d$ and AB$=t$,

Then the refractive index is given by the relation

$$\mu = \frac{\sin. PBQ}{\sin. ABD} = \frac{\tan. PBQ}{\tan. ABD}$$ since the angles PBQ and ABD are small.

$$\text{Hence } \mu = \frac{AD/AF}{AD/AB} = AB/AF = t/(t-d) \quad . \quad . \quad . \quad . \quad (1)$$

To investigate the limits of error the following procedure is adopted.

Let $\mu$ denote the refractive index

Then $\mu = t/(t-d)$

To obtain the error in $\mu$ due to errors in $t$ and $d$ equation (I) is differentiated as follows :—

$$\delta\mu = \frac{\partial}{\partial t}\left(\frac{t}{t-d}\right)\delta t + \frac{\partial}{\partial d}\left(\frac{t}{t-d}\right)\delta d$$

$$= \frac{-d}{(t-d)^2}\delta t + \frac{t}{(t-d)^2}\delta d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The values of $\delta$t and $\delta$d are, from the nature of the measurements, equally likely to be positive or negative, and hence the negative sign attaching to the coefficient of $\delta$t has no practical significance·

From (I) $t-d=t/\mu$
and $d=(\mu-1)/\mu$.

Hence by eliminating d from (1) and (2)

$$\delta\mu = -\frac{\mu(\mu-1)}{t}.\delta t + \frac{\mu^2}{t}\delta d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

As the real test of accuracy is the ratio of the error to the amount measured, it is better to write equation (3) in the form

$$\delta\mu/\mu = -\frac{\mu-1}{\mu}.\delta t + \frac{\mu}{t}\delta d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)\text{A}$$

From this equation the following facts are clear :—

(1) For a given thickness of material more accurate results are obtained with minerals of low refractive index than with those of high refractive index.

(2) In determining the refractive index of any mineral more accurate results are obtained from thick than from thin sections.

Since the great majority of minerals have refractive indices between 1·4 and 2 it will be sufficiently practical to consider the variations between these limits.

The values of $\delta$d are of a definite order of magnitude, which, according to my own observations, approximates to ·01 m.m.

Mr. Sorby,[1] who has made a series of experiments with this method, states that "an accuracy of ·001 inches can easily be obtained.".

The value of $t$ may be ascertained to any required degree of accuracy, but in practice it is usually determined by the same method which is used in obtaining the value of d. Thus, the value of $\delta t = \delta d = \cdot 01$ m.m.

If the thickness of the plate used be such that the co-efficient of $\delta d$ in (3) A be not greater than unity, then $\mu$ can be calculated with considerable accuracy,

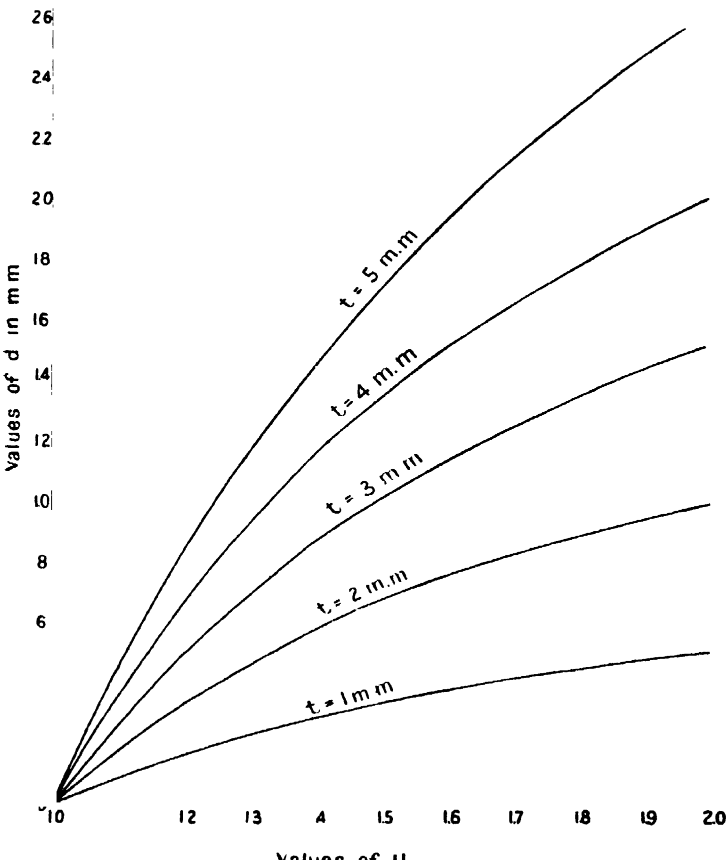



FIG. 3.

[1] H. C. Sorby: "On a Simple Method of Determining the Index of Refraction of Small Portions of Transparent Substances," *Min. Mag.*, 1877, Vol. I., pp. 97-98.

The maximum errors which can occur in determining refractive indices of the values 1·4 and 2 are shown to be respectively as follow:

Suppose $\mu/t=1$ and $\delta t=\delta d=.01$ m.m.
and also $\mu=1{\cdot}4$;

Then substituting in equation (3) A gives

$$\delta\mu/\mu=-\frac{\cdot 4}{1\cdot 4}\times\cdot 01+\cdot 01$$
$$=-\cdot 0029+\cdot 01.$$

Since $\delta t$ and $\delta d$ may each be either positive or negative this gives a maximum value of $\delta\mu/\mu=\cdot 0129$, which is an error of 1·29 per cent.

Thus a number of observations should give the value of U correct to much less than one per cent.

Again, suppose $\mu/t=1$, $\delta t=\delta d=\cdot 01$ and $\mu=2$; the substitution in equation 3 A gives

$$\delta\mu/\mu=-\tfrac{1}{2}\times\cdot 01+\cdot 01\ ;$$
$$i.e.,\ \delta\mu/\mu=-\cdot 005+\cdot 01,$$

and this gives a maximum value of .015 if $\delta t$ and $\delta d$ are of opposite sign. This is an error of 1·5 per cent., and a number of observations would reduce the probable error to much less than one per cent. As $\delta t$ and $\delta d$ are measured in millimetres this indicates that

(1) For minerals with relatively low refractive indices a thickness of material not much less than 1·4 m.m. should be used to give values correct to one per cent;

(2) For minerals with relatively high refractive indices a thickness of material not much less than 2. m.m. should be used to achieve a similar result.

Mr. Sorby[1] states that if the thickness be from ⅛th to ¼ inches " the errors ought to be limited to the third place of decimals."

Most that is contained in the foregoing may be represented graphically as follows:—

If the curves $\mu=t/(t-d)$ be plotted for different values of $t$, making $\mu$ and $d$ the variables, a series of rectangular hyperbolas is obtained, all passing through the point 0,1 and all being asymptotic to the line $d=t$ for the particular value of $t$ belonging to it.

The curves for $t=1$, 2, 3, 4 and 5 m.m. are represented in the accompanying diagram. From these it is apparent that as $\mu$ increases the curves become flatter, bending over to become asymptotic to the lines $d=t$. Hence on any curve a small change $\delta d$ makes a greater change in the value of $\mu$ when $\mu$ is large than when $\mu$ is smaller. If the ratio $\delta\mu/\mu$ be tested it will be found to increase continuously with $\mu$, and this corresponds to statement (1) on page 2.

Again, as $t$ increases the curves rise more steeply, which means that for any given value of $\mu$ the change $\delta\mu$, and hence the ratio $\delta\mu/\mu$, is smaller for thick than for thinner plates of material, and this corresponds with statement (2) on page 2.

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1 *Loc. cit.*

**ERRATA** PAGE 833

| | | | |
|---|---|---|---|
| Analysis No i | | Analyst | J.C.H.Mingaye |
| .. | .. ii | .. | L.A.Cotton |
| .. | .. iii | .. | L.de Launay |

[*From the Proceedings of the Linnean Society of New South Wales, 1914, Vol. xxxix., Part 4, November 25th.*]

# THE DIAMOND-DEPOSITS OF COPETON, NEW SOUTH WALES.

BY L. A. COTTON, B.A., B.Sc., FORMERLY LINNEAN MACLEAY FELLOW OF THE SOCIETY IN GEOLOGY.

(Plates xc.-xcii.)

CONTENTS.



## i. INTRODUCTION.

The Copeton diamond-field has its centre of activity at Copeton, a small township on Cope's Creek, about two miles above its junction with the Gwydir River. It is thus on the western edge of the New England tableland. The present paper is the result of observations made during June, 1909, May, 1910, and January, 1913. A number of investigators had previously given some attention to the field, and several papers have been published in connection with it. The earliest report which I have been able to trace, is that of Mr. C. S. Wilkinson(10) to the Surveyor-General, in July, 1873. In this report, he refers to the operations of the Borah Tin and Diamond Mining Company on the alluvial drift, which, he suggests, has been derived from the denudation of the deep leads. It is now known that this suggestion is the correct one. Other reports have been furnished from

time to time by officers of the Department of Mines, the chief of these being that of W. Anderson(2) in 1887. This communication was accompanied by a geological map of the district in the neighbourhood of Copeton. This map, somewhat modified and added to, has been incorporated in this paper. Another report of some value is that by G. A. Stonier(8) in 1894. An excellent summary of the work accomplished, up to the date of publication, was given by Mr. Pittman(7) in his book, "The Mineral Resources of New South Wales," which appeared in 1901. The most interesting fact, from the scientific standpoint, was the discovery of a diamond in its true matrix by Messrs. Pike and O'Donnel in 1904. An account of this was published in the Annual Report of the Department of Mines for that year.

More recent contributions to the literature of the subject have been made by Professor David(4), Mr. J. A. Thompson(9), and Mr. A. R. Pike(6).

### ii. The Nature of the Leads.

The diamond-bearing drifts fringe the depression which lies between Cope's Creek and the Gwydir River. (See Plate xci., fig 2). As the first diamonds discovered were won from *recent alluvials*, these will be first described.

Reference has already been made to the fact that diamonds were first found by miners in search of alluvial tin. In all these cases, these gems had been redistributed from Tertiary river-gravels. By this process, small quantities of these gravels were added to relatively large masses of recent river-gravels. In consequence of this, it is at once apparent that the diamonds must be scattered through a much greater amount of barren river-gravel than was the case in the old leads. In exceptional cases, where the denudation of the Tertiary gravels was rapidly effected, the recent alluvial deposits have proved payable. Koh-i-noor deposit and the old football-ground at Copeton are examples of this type of occurrence. The former place lies between two well defined portions of the Tertiary lead. The diamonds are here found distributed through a mass of basalt-boulders, which have been worn down from the neighbouring hills. These boulders

have become encrusted and cemented by calcite, resulting from the decomposition of the basalt itself. At the latter place, the diamonds have been derived from the destruction of a tributary of the main lead, which connected Soldier Hill with the Round Mount.

Though a few diamonds have been won from these recent deposits, by far the greater number have been recovered from the Tertiary deposits. In rare cases, the basalt-capping has been denuded, and the gravels lie exposed at the surface. These original deposits are readily detected from the recent alluvials, both by their position and the nature of their gravels. Examples of such deposits are the Streak of Luck, and the Sandy Block. The greater part of the Tertiary gravels, however, are now to be found underlying basalt-flows at various depths from the surface.

The age of the diamond-bearing gravels can be determined only relatively to the rocks between which they lie, as no definite internal evidence has yet been found. Though lignite occurs in several of the mines, no definite plant-remains have been obtained from this locality.

The granites are to be correlated with those at Ashford, which have been stated to intrude Permo-Carboniferous sediments. The coarse grain of the granite indicates that it must have consolidated under a considerable thickness of the sedimentary rock. As, however, but little of the latter remained at the time when the basalt-flows occurred, a considerable interval must have elapsed between the intrusion of the granite and the formation of the deep leads.

The evidence of fossil leaves, from other leads in New England, points to a late Tertiary age for the basalts of the plateau. In the lack of any more definite evidence, therefore, the Copeton diamond-deposits may be regarded as of late Tertiary age.

*Tertiary gravels.*—The nature of the diamond-bearing drifts has obviously been determined by the character of the country over which the prebasaltic streams flowed. The main lead at Copeton has had its course entirely in granite. This rock is of an aplitic character, and, being composed chiefly of quartz and felspar, has, as its products of decomposition, quartz-grains and

kaolin. The latter product, on account of the ease with which it is carried in suspension by running water, can be deposited only where the water is comparatively still, as in lagoons. Conversely, the occurrence of any kaolin-deposits implies comparatively still-water conditions of deposition.

A few small tributaries of the main lead have intersected the sedimentary rocks (chiefly clay-slates), and have thus locally introduced a third factor.

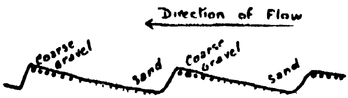
As the processes of river-development do not vary with geological time, the Tertiary leads exhibit features in common with present-day streams. Large boulders, for example, occupy a great portion of the old river-channels. These are often so large as to be mistaken for portions of the walls or bottom of the river-channel, and are a source of continual trouble and perplexity to miners. In general, of course, there is an arrangement of the coarsest material at the base of the drift, and a diminishing coarseness of texture with distance from the channel-bed. This type-arrangement is subject to modification in which a number of coarse bands mark the temporary level of the stream.

The drifts are almost invariably of a reddish colour, which is due to the staining effect of the iron-oxides leached from the overlying basalts. The thickness of the drifts varies very greatly, even at short distances. This may be attributed to two causes, the first being the irregularity of the bed of the stream, and the second, the differences in grade; a swiftly flowing current, on a steep grade, tends to sweep the channel-bed free from all loose material.

The greatest thickness of drift observed at Copeton was at the Round Mount. Here a depth of 25 feet was encountered. The "wash," as it is called, differs from the main bulk of the gravel in being coarser in texture and more compact. At the Round Mount, the bulk of the gravels consists of small quartz-grains from 2 to 5 mm. in diameter. The wash, on the other hand, consists chiefly of quartz-pebbles from 5 mm. to 3 cm. in length. The pebbles are of the normal stream-type, being ellipsoidal in form. The slightly predominant tendency of these pebbles to lie with their long axes sloping upwards towards the south-east,

indicates that the flow was probably in that direction. Amongst the quartz-pebbles in the wash are to be found a number of blue-coloured rocks, subangular or ellipsoidal in form, and ranging from 2 to 24 cm. in length. This particular band of rock is 20 cm. in thickness, and lies between gravel and drift of normal character. The existence of these bands of wash, at different levels in the drift, is doubtless due to the action of minor floods. Andrews has shown that the work of aggradation is performed in the interflood period. Each moderate flood excavates some of the material aggraded during the interflood period. The largest, or true flood, removes the whole of this material, and corrades the channel. As the flood subsides, aggradation commences; matter held in suspension gradually settles; the coarser material, on account of its greater weight per unit of surface, sinks first, and thus a grade from coarse to fine material is established. Pebbles of greater density associate with larger stones of less density; and, finally, sand covers the whole. The effect of a moderate flood, on the deposit, following a large flood, will now be considered. The moderate flood has not sufficient energy to remove the whole of the material deposited after the large flood, but it can remove some of it. As this moderate flood begins to subside, deposition takes place, and another series is formed having the coarser pebbles at its base. Thus it is possible for many zones to be formed. The coarser pebble-zones formed in this way constitute the layers of wash. The lowest layer of wash is usually the most payable, as the diamonds are larger and more abundant. The layers of wash are somewhat irregular. The bottom-layer follows the contours of the channel-base, which is generally very uneven. The upper layers of wash, on the other hand, conform very uniformly to the horizontal, as they are built up on the loose sands and gravels, which readily adjust themselves to the level under the influence of running water. Yet there is a degree of irregularity: the wash seems to be cut off very abruptly in places, and no clue seems to be afforded by which it may be traced. A very striking illustration, which may explain this irregularity, was observed in the bed of Cope's Creek, near its junction with the Gwydir. A recent flood of

considerable strength had passed along the channel of the stream, but, at the time of observation, only a small stream was running. The notable feature was the arrangement of the sands and gravels in the creek-bed. These were deposited in wedge-shaped blocks, having the thin edge of the wedge pointing up-stream. A diagrammatic section of these deposits along the length of the tream is given in Text-fig. 1. This would seem to correspond to Andrews' step-like structure in the evolution of stream-development. The slopes were from 20 to 30 feet in length, and the steps from 2 to 3 feet in height. The depressions caused by these steps were of the shape of isosceles triangles (Plate xci., fig. 2), having the apex of each triangle pointing down-stream, and the base perpendicular to the direction of flow. The length of the base varied from 6 to 10 feet, and the height of the triangles from 8 to 10 feet. The depressions were in sand having a grain-size from 1 to 3 mm. The upward-sloping surfaces of the gravels were covered, to a depth of about 2 inches, with coarse pebbles, from 3 to 7 cm. in diameter. If these were buried under a further load of drift and sand, and then covered by a basalt-flow, they would present the same discontinuity, in the beds of wash, as are met with in the deep leads. The study of such features should be of value in the prospecting of deep leads.



Text-fig. 1.—Section of bed of Cope's Creek, parallel to the stream.

In a deep lead, there are four well marked zones in the materials deposited, any or all of which may be present. These are—

(1). The coarse gravels known as the wash

(2). The medium-grained sands and gravels constituting the main bulk of the deposits.

(3). A deposit of fine mud or clay.

(4). A deposit of vegetable-débris, which has, not infrequently, been converted into lignite.

Of these, the wash has been partly discussed in relation to its occurrence at the Round Mount. It has already been noted that the leads under consideration are entrenched in granite, save where a few tributaries have intersected the slate-formation.

It is to be expected, therefore, that the gravels and sands would consist of simple products, and, with regard to the great bulk of them, this is true. There are, however, to be found, intersecting the granite, a great number of small reefs containing many different minerals. It is from these reefs that the bulk of the wash is made. The hard parts of the wash comprise quartz, tourmaline, topaz, jasper, zircon, cassiterite, garnet, and diamond. The soft parts are made up of kaolin, decomposed granite-pebbles, and decomposed pebbles of basic igneous rock.

In the main lead, the wash is fairly coarse, the average size of the pebbles ranging from 1 to 8 cm in diameter. Occasional boulders are met with, from this size up to several feet in diameter.

A large percentage of the hard wash-pebbles are quartz, probably more than 90 %; and these can have been derived only from the reefs in the granite. Tourmaline-pebbles are next in order of abundance. These are not of large size, being, as a rule, rather less than 1 cm. in length. They are generally more bean-shaped than the quartz-pebbles, this, no doubt, being due to their formation from the "pencil-tourmaline" so common in the quartz-reefs. The proportion of tourmaline to quartz-pebbles varies greatly from place to place, but rarely exceeds 5 %. The topaz, which occurs in the wash, has, no doubt, been derived from the same source as the tourmaline, but the amount present is very small, and is only noticeable when concentration has been effected. A similar statement also applies to the garnet found in the leads. These gems are small, rarely exceeding 4 mm. in diameter. It is this mineral more than any other which is constant in its association with the diamond. Sapphire is only occasionally met with in association with the Copeton diamonds, and zircon is a rare associate, but special characteristics distinguish the wash from different parts of the lead. The thickness, the degree of coarseness, and the relative amounts of the various constituents, are all very variable quantities. At Soldier Hill, a number of sharp, angular quartzes are present in the wash, so that, doubtless, a reef is close to this deposit. Here, also, a number of jasper-pebbles occur. These are grey stones, much

flattened and waterworn. It is evident that they have travelled a considerable distance, having probably been derived from jasperoid bands in the slate-formation. At Benson's farm, better known, perhaps, as the Old Farm, the wash is unusually coarse, boulders up to 20 cm. in diameter being very common.

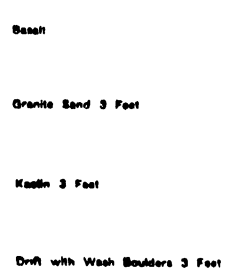
In some places, the wash has undergone secondary change, as at Kirk's Hill, and the Banca mines. Here, a very common feature is what is locally known as the iron-band. This is a layer of wash which has been cemented by the infiltration of iron-bearing waters. It so happened that the wash, thus altered, was rich in diamonds, and a considerable quantity of it has been profitably mined. It was found that the band was too hard to be crushed without risk of fracturing the diamonds. This difficulty was overcome by heating the material on iron.plates, care being taken not to raise the temperature to the combustion-point of the diamond. The differential expansion of the diamond and its host caused the stones to become freed by this method.

The second zone of the deep lead deposits—*the drift*—constitutes by far the greatest bulk of the material. The sands comprising this possess a grain-size of about 2 to 3 mm., and frequently enclose one or more subsidiary layers of wash. The maximum thickness observed was about 35 feet at the Round Mount. Some of the grains are waterworn, while others are angular, but there is nothing very distinctive about the main mass of the material. It is not found to contain diamonds in payable quantities, even where the gems are most abundant, though occasional stones have been recovered from it.

The third zone - comprising fine mud and clay—occurs only at a few places on this field. At Rider's lead, the most noticeable feature is the presence of a large body of pipeclay, which overlies the gravels of the diamond-bearing wash. This portion of the lead has been worked for nearly a mile, and the bed of pipeclay has been found practically continuous throughout that distance. The clay is a soft, white material, almost pure kaolin, and has an average thickness of about 2 feet. Below it, lies the drift, and below this, again, is a bed of wash, from a few inches up to a foot in thickness. The whole series is covered by a con-

siderable thickness of alluvium, in some places as much as 50 feet in depth. The lead runs from south to north, and only the latter end is covered by basalt.

Again, between the Star of the South Mine and Davis' block, a section of the lead is to be seen, where it has been exposed by mining operations. In this case, a rather unusual arrangement occurs (See Text-fig.2). The pipeclay-band, which is 3 feet in thickness, is overlaid by a fine granite-sand, and rests on gravels, the pebbles of which have a diameter of about 4 mm. This deposit lies at the junction of the two main streams of the Tertiary lead, and is capped by basalt.




Text-fig.2.—Section of the Tertiary Lead between the Star of the South Mine and Davis' Block.

The fourth zone mentioned —that comprising vegetable-débris - is of relatively rare occurrence on this field. The most typical example is that of the Crown Jewel Mine. Here, the vegetation, which has been converted into lignite, overlies the drifts, and is of considerable extent. A tunnel was driven through the drifts for more than 100 feet, and the roof of this drive was in lignite for the whole distance.

### iii. Physiography.

In an investigation of the kind embodied in this paper, the two phases which are of most physiographic interest are evolutionary ones. The problems presented are – How has the present topography been developed; and what is its relation to the pre-Tertiary condition? Several elements have contributed to the process, and the chief of these are as follow: (1) denudation, (2) earth-movements, and (3) volcanic phenomena.

If it were possible to replace, in its original position, the mass of material removed by the agency of denudation since the

basaltic period; to remove the basalts entirely; simultaneously to readjust, in their proper chronological order, the results due to earth-movements; there would then appear, in its original state, the topography of the pre-basaltic period.

Mr. E. C. Andrews has given an excellent general account of the physiography of northern New England. He has shown certain stages of peneplanation, the youngest of which has left its record as the Stannifer peneplain; and the physiography of Copeton is dominated by this feature.

A study of the contours on the accompanying geological map reveals three topographical units. These are:—

(1). A relatively low-level area bounded, on its north and east sides, by the Gwydir River. This is about 2,200 feet in height.

(2). An area of moderate relief situated north of Cope's Creek and the Gwydir. This area has an altitude of about 2,800 feet.

(3). An area of relatively high relief situated to the east of the Gwydir, and to the south of Cope's Creek. This area attains an altitude of as much as 3,400 feet.

The first of these is wholly in the Oakey Creek granite-area. I examined about one hundred square miles of this area, but failed to obtain any evidence that it had been covered by basalt. If such has been the case, denudation has removed all trace of the lavas. The channel of the Gwydir is about 200 feet below the general level of this area.

The second unit presents more variety in its geological structure. The basal rock is granite. Two types—the Oakey Creek granite and the Acid granite—are present, and these are separated approximately by a tributary of Cope's Creek (see Plate xcii.). There are also masses of clay-slate included in the area, mainly to the east of the Auburn Vale Creek. Basalt overlies a considerable portion of each of these rocks. This area represents the denuded surface of the Stannifer peneplain.

The third unit is composed of the Acid and Tingha granites, and basalt has been found only along old valleys cut in these structures. This area also represents part of the original Stannifer peneplain. Further data are yet required for the solution of the problem. These are supplied by a knowledge of the positions

and directions of flow of the Tertiary streams. These may be seen by a reference to the accompanying geological map, on which they are represented by thick black lines.

As a preliminary step towards solving the problems connected with the pre-Tertiary stream-development, it will be well to consider the present rivers and their origins. The chief of these are the Gwydir River, and its tributary, Cope's Creek. The question arises, has the course of the Gwydir been determined by the re-opening of some Tertiary stream, or has it had its direction controlled by some large structural feature developed subsequently to the basalt-period?

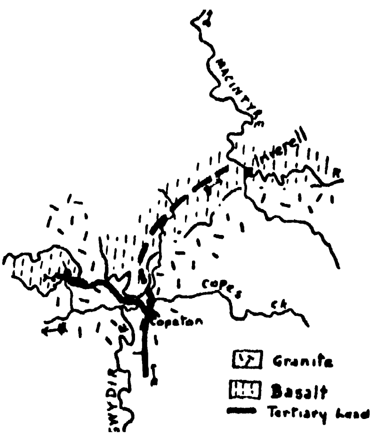
The accompanying map shows that a pre-basaltic stream flowed from Oakey Creek to Copeton, in a direction approximately parallel to the Gwydir, but in a contrary direction. Moreover, the distance between the two streams is less than two miles, while the difference in their levels is about 100 feet. The great instability of such a system is opposed to the existence of the Gwydir as a pre-basaltic stream. Again, it would be strange indeed if the basalts, which covered the Oakey Creek lead with a thickness of several hundreds of feet of basalt, had not filled the valley of the lower adjoining river. The fact that no trace of basalt has been found on the low-lying area to the south-west of the map, is also opposed to this view. It may be concluded, therefore, that the present Gwydir has been developed in a direction quite independent of the pre-basaltic drainage-system.

If the present course of the Gwydir be regarded as post basaltic, its position must be due either to haphazard denudation, or to some definite structural feature. The presence of the relatively low-lying block, bordered on its north and east sides by the Gwydir, is the factor which serves to discriminate between these two explanations. It is highly improbable that the processes of denudation can have exerted such a selective influence on the low area lying to the south and west of the Gwydir, while steep escarpments rise abruptly from the other side of the river. The assumption of a faulted block, on the other hand, accounts both for the low level of the area discussed above, and also for the marked change of direction of the Gwydir at its junction with

Cope's Creek. This explanation, moreover, implies that, at the period of basaltic intrusion, this block-faulted area was at a much higher elevation, and, consequently, more likely to have escaped being flooded with lava; and it has been pointed out that no evidence of basalt was found on this area.

It thus appears probable that the Gwydir is a post-basaltic stream, which has followed the direction of the two faults bounding the north-east corner of a fault-block.*

The reconstruction of the pre-basaltic physiography, then, involves the elevation of the fault block into its original position. If we suppose this to be done, there remains only the removal of the basalts to restore the conditions of the pre-basaltic physiography. The presence of river-gravels, and of V-shaped sections of basalt lying on granite-foundations, enables a large amount of this imaginary construction to be readily performed.




Text-fig. 2a --Map showing the Tertiary and Recent river-systems of the Gwydir and Macintyre near Inverell.

The final result of this re-adjustment of the effects of natural processes transforms the area into a denuded pene-plain at an elevation of 3,000 feet above sea-level. The discussion on the disposition of the Tertiary leads indicates that the pre-Tertiary streams united to form a north-flowing river. This tendency of the pre-basaltic drainage to flow north is in marked contrast to the present trend, which is towards the west.

From the junction of Auburn Vale Creek with Cope's Creek, a broad basalt-flow trends northwards towards the western side of the town of Inverell. For about half the distance, the flow is limited on each side by granite; but, near Inverell, only the eastern boundary is

* Further evidence of faulting occurs to the west at Keera Station.

well marked. The level of the basalt on the western side is above the peneplain-surface of the granite-area. This flow undoubtedly represents a pre-basaltic valley, which was completely obliterated by the lava-flows. Subsequent denudation has exposed the granite along the eastern side, and partly on the western side (See Text-fig. 2*a*).

As the pre-basaltic Gwydir has been traced directly into the southern, truncated end of this flow, there can be no doubt that the Gwydir originally continued in this direction.

Moreover, it is clear that the Macintyre at Inverell has been redeveloped along the course of a pre-Tertiary stream from Newstead to Inverell. Thus it would appear that the Macintyre-Gwydir originally formed one stream-system, which has been severed by the large basalt-flow extending from Copeton to Inverell.

### iv. The Distribution of the Diamond-leads.

The subject-matter of this Section will be rendered clear by reference to the accompanying geological map (Plate xcii.). This map is practically that of Mr. Anderson, published in 1887. A few additions and alterations, including the contours, have been made by the author. Previous workers have held the opinion that the main Tertiary stream flowed west from Copeton to Bingara. It has been stated, in support of this hypothesis, that the size of the diamonds found in the river-gravels decreases from Copeton towards Bingara. It has been argued that the largest diamonds would remain nearest their source of origin, and the smallest would be carried farthest down stream. This argument is, no doubt, correct, but the converse is not, in this case, true. The observation of numerous aneroid readings, which were checked and standardised, has shown that the Tertiary lead on the north side of the Gwydir has not flowed towards Bingara, but in the opposite direction. Some other reason must, then, be assigned to account for the fact that the diamonds are larger at Copeton than at Bingara.

The levels observed are recorded on the sketch contour-map. The gaps between the remnants of the basalt-leads have been

examined, and the Tertiary stream-channel reconstructed as shown. A short description of the various places, where diamonds have been found, will serve to connect these, and to illustrate their relationships.

The most southern claim is that known as Rider's Lead. This lead heads on the present divide, between Maid's Creek and Sandy Creek, at an elevation of about 2,600 feet above sea-level. This is near the junction of the Acid with the Tingha granite, but the lead itself lies chiefly within the Acid granite-area. Very little basalt is now present, and the greater portion of the lead is now concealed by alluvial deposits at a depth of about 50 feet. The characteristic feature of this occurrence is the zone of pipeclay, which overlies the drift and wash. Owing to the neglected state of the workings, I was not able to investigate underground; but, from information supplied by Mr. Skippen, it would appear that the body of wash was not more than a few inches in thickness. This was overlaid by about three feet of rather coarse drift (containing pebbles up to 1 cm. in diameter), and the whole covered by two or three feet of pipeclay. The basalt-capped part lies three-quarters of a mile below the head of the lead. It is probable that, when this lower portion was overwhelmed by basalt, a lake was formed in which the fine kaolin from the decomposition of the felspars was deposited. There is no evidence that the head of the lead was ever covered by basalt. Little success has attended the exploitation of the deposits underlying the basalt, most of the diamonds having been won from that part underlying the alluvial deposits.

The minerals associated with the diamond in this lead are tourmaline, topaz, tinstone, jasper, and garnet. The diamonds, as usual, were recovered from the wash, in which they were irregularly distributed. Several good finds were made in small potholes. The stones were of better size and quality than the average production of the Copeton field, and numbered about three to the carat. Bort is also recorded from this locality.

Following the lead north, the next place where diamonds have been found is at Kenzie's claim. Here the lead has been almost entirely swept away by the present creek, but a small area of

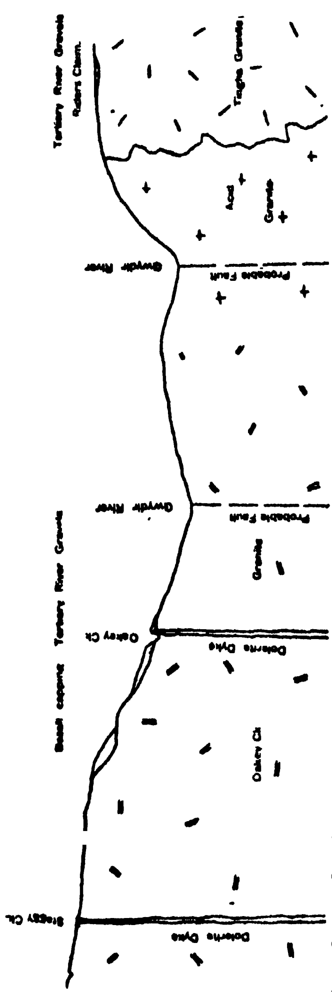
basalt, considerably less than an acre in extent, still remains. The discovery of diamonds here is only of importance, for the purpose of this paper, as a piece of evidence as to the course of the lead.

At Collas' Hill, diamond-bearing drifts have been worked with some success. Here, the basalt has been intersected by the present stream-course, and has exposed the Tertiary gravels on the side of a hill. These deposits were prospected by means of tunnels, driven at the level of the wash, which stands at an elevation of about 2,280 feet. The diamonds found here averaged about four to a carat, and contained a number of triangular, flattened crystals.

The Streak of Luck Mine is situated on the next remnant of the Tertiary lead. Here the basalt has been entirely denuded, and the gravels lie either exposed at the surface, or buried under a few feet of alluvial. The level of the wash at this mine is about 2,250 feet. The diamonds from this locality averaged about four to the carat.

The Deep Shaft Mine adjoins the lease just mentioned. The diamond-bearing drifts are here covered by basalt, varying in thickness from 50 to 130 feet. This has been one of the most productive mines on the field. A small tributary from the south-east joined the lead at this point. This has introduced, into the lead, boulders of clay-slate from a small area of this rock about half a mile distant. In places, these boulders are several feet in diameter, and overlie the sandy drift. The wash is normally about one foot in thickness, and is covered by sandy drift, the grainsize of which is from 3 to 6 mm. The diamonds occur in the wash, and are associated with quartz, topaz, tourmaline, garnet, sapphire, zircon, and tinstone. The gems are found unevenly distributed, often occurring in clusters where concentration has taken place. It is recorded that 150 carats have been recovered from a single load of wash-dirt. It is noteworthy, that the diamonds won from this mine are larger than those from the lead above this place. The stones average three to the carat, and are of good quality. From 40 to 50 per cent. of the stones are white, rather more are a light yellow, while a few are brown

and green. Well developed octahedral crystals are conspicuous; probably 6 to 8 per cent. of the diamonds being of this nature. A number of the crystals exhibit twinning. Pieces of bort, several carats in weight, have also been found at this mine.



Text-fig. 3.—Section from Staggy Creek to Rider's Lead, showing the relations of igneous rocks and faults.

The lead next passes through Davis' block. Here it is also concealed by basalt, though the depth of the wash from the surface is lessened by the fact, that a small stream has removed a considerable portion of the basalt-capping. The lead, at this point, swings round from a north-east and takes a north-west course.

At the Koh-i-noor Mine, which is situated about 150 yards beyond the last-mentioned block, the basalt has been removed from the lead on its western side. A section of the deposits (see Text-fig 3) shows that the bedrock is a very decomposed granite. Upon this rests a body of gravel, some three feet in thickness. There is no prominent band of wash in this, but the whole consists of small quartz-grains and pebbles about 4 mm. in diameter, which have been derived from the decomposition of the granite. Above this lie three feet of pipeclay of the same nature as that noticed at Rider's lead. This, again, is covered by three feet of fine granite-sand. The whole section has been exposed by tunnelling, and is overlaid by basalt. Immediately to the west of this is situated the redistributed, Tertiary gravels previously mentioned.

The Star of the South has been more productive than any other mine on this field. The bulk of the material mined was hauled from Skippen's shaft, which is 90 feet in depth. The shaft was sunk through basalt until the underlying granite was encountered. The sinking was then continued into the granite, and two drives put in to intersect the wash, and so drain the lead. Both drives intersected a dyke nearly at right angles. In one drive, the dyke attained a thickness of one foot, and in the other it was six inches. The dyke-material was decomposed to a yellow clay. Boulders of this clay were found in the diamond-bearing wash in association with the gemstones.

Adjoining the Star of the South Mine, is Benson's block, better known as the Old Farm. The lead is here covered by 60 feet of basalt, and a considerable amount of water was present in the drift and gravels. The wash was of a very coarse nature, and contained a great number of quartz-boulders up to six inches in diameter. Boulders of granite were also abundant. The diamonds recovered from this mine were similar to those found in the Star of the South, and averaged from three to four to the carat. This mine is of special interest, as here the lead terminates abruptly at the northern end. This disappearance of the lead is explained by the fact that, at this point, the Tertiary stream-channel has been reopened by a recent watercourse, which has removed all traces of the diamond-bearing gravels. The recent stream has its channel on the floor of a steeply sloping gully, less than one quarter of a mile in length, and joins Cope's Creek at a very rugged spot. Beyond this, the lead must have crossed the present position of Cope's Creek. About half a mile to the north-west of this point, there is a large body of gravel and wash at an elevation some 20 feet lower than the gravels at the Old Farm. There can be no doubt that this was part of the main Tertiary stream-channel. The gravels have been prospected by means of tunnels, but no diamonds were found. A tributary flowed in at this spot from the south-west, and recent denudation has exposed, in several places, the gravels deposited along its course. These deposits have been exploited, but without success. The course of the main Tertiary stream has now been traced from Rider's

lead, on the south, to a spot half a mile to the north-west of Cope's Creek on the north. Beyond this point, the Tertiary river-system is completely hidden by basalt-flows as far north as Inverell.

The western lead has not yet been considered. This was a large tributary stream, which flowed from a spot 10 miles west of Copeton, and joined the main stream at the town itself. The course of this lead is nearly parallel to that of the Gwydir, but the fall is in the opposite direction. The continuity of the lead has been destroyed by several creeks, which have worked back from the Gwydir. The effect of this is, that there now exist a number of isolated basalt-areas with a linear arrangement, yet separated by steeply flowing creeks. The extreme western limit of the lead, which has proved diamond-bearing, is at Oakey Creek. Here a north-flowing tributary of the Gwydir has intersected the east-flowing Tertiary lead, leaving the gravels exposed at the surface on each side of its valley. The deposits were worked by means of tunnels, and both diamonds and tinstone recovered from the wash. It was while driving a low-level tunnel in the granite underlying these deposits, that Messrs. Pike and O'Donnel met with a very remarkable occurrence. The tunnel was found to intersect a large body of decomposed igneous rock, and it was noticed that a great deal of this was found in the wash in association with that part of it which was richest in diamonds. The dyke-rock is a dolerite. It does not outcrop on the hill-slope, but is entirely covered by basalt.

The diamonds found at Oakey Creek are rather smaller than the average Copeton diamonds, ranging from four to five to the carat. About half the stones recovered are white, and most of the remainder straw-coloured. Few octahedra have been found, and there is no record of bort having been discovered.

The lead continues through the hill forming the watershed between Oakey Creek and Kirk's Creek, and the gravels again outcrop on the eastern slope of this hill. Here another drive, known as Dodd's tunnel, was put in to reach the wash near its bottom-level. This tunnel, like that at Oakey Creek, also intersected a dyke, boulders of which were in the adjacent diamond-bearing wash.

About half a mile further east is Kirk's Hill. This claim is renowned for having produced the richest find of diamond-bearing wash in the district. It is reported that, from four loads of wash-dirt, 1,100 carats of diamonds were recovered. A number of large boulders were present in the wash, and these seem to have acted as a series of ripples in concentrating the diamonds. The usual associates of the diamond, topaz, tourmaline, tinstone, garnet, and quartz were also found here. Another decomposed dyke also occurs in association with these deposits. The gravels overlie the dyke in part, and soft, yellow, decomposed boulders, derived from it, are present in the wash. The wash here is at an elevation of about feet. A notable characteristic of the wash at this mine is the presence of what is known as the "iron-band " This name is applied to a layer of wash cemented by iron oxide of a very hard and tough character.

Following the lead further east, the Banca Mine is reached. This lies on the eastern side of Kirk's Creek, and was one of the earliest worked mines. Here, again, a dyke was met in one of the tunnels. The "iron-band" was also found at this mine, where it reached a thickness of two feet, and rested on a granite-floor. Tinstone was found associated with the diamonds.

Beyond Kirk's Hill and on the western side of the Malacca Creek, is another isolated area of basalt covering Tertiary gravels. The Malacca Mine is responsible for the exploitation of these deposits. The basalt has here been denuded so that the lead outcrops on both the eastern and western sides of the hill. The lead lies at the southern extremity of a basalt-capped hill, which bears north and south : it still maintains its east and west trend, and so outcrops on both the east and west sides of the hill. It has, however, narrowly escaped entire destruction, for the gravels, lying on its southern bank, have been exposed in several places on the southern slope of the hill. The distribution of the gravels is still mere obscured by the fact that a tributary stream joined the main lead from the south-west at this point. The result of this configuration is, that the wash outcrops at different levels at various parts of the hill. This is all very confusing at first, and the failure of the prospectors to interpret these facts has made

the mining of these deposits a very difficult matter. There is sufficient tinstone present in the wash to make it worth while to recover it, when mining for diamonds. The diamonds are small, ranging from four to five to the carat. Bort is only rarely found at this mine. Here, again, another dyke was met in driving a tunnel into the hill from the west side. The tunnel was driven in a direction about north-east, and two cross-cuts were put in to the north-west, at a distance of 100 feet apart. Both these cross-cuts intersected a dyke. In the more western one, the dyke attained a thickness of 8 feet, but, in the eastern one, the thickness was only 2 feet. It is evident, from the position of this dyke, that the diamonds of the Malacca Mine lie on the downstream side of it. Accompanying the diamonds in the wash were numerous, small, bluish-coloured boulders, from 2 to 3 inches in diameter, derived from this dyke.

To the east of this occurrence, the lead has been denuded by the Malacca Creek, which is a short, steep stream flowing south into the Gwydir. On the eastern side of this creek, the basalt is again to be found covering the Tertiary gravels. This part of the lead has not yielded diamonds in payable quantities, and no local name has yet been assigned to it. The deposit is here from 10 to 12 feet in thickness. A band of coarse wash, containing quartz-boulders up to 2 inches in diameter, occurs about 3 feet from the granite-floor. A few clay-boulders were also noted, and these must have been derived from some dyke in close proximity. About 100 yards to the north-west is another body of drift, some 20 feet higher than the drifts just described. This also contains a number of clay-boulders, and may have been a tributary stream.

To the south-east of the deposit just described, is situated the outcrop of gravels known as Soldier Hill. This was one of the earliest mines worked for diamonds. The discovery of the gems was first made among the sand-grains on a soldier-ants' nest, and hence the name of the mine. The lead here turns to the south, and, beyond the south end of Soldier Hill, has been entirely denuded. Both diamonds and tinstone have been recovered from the wash. The stones recovered average from 3 to 4 to the carat. In this mine, besides the wash on the granite-floor, a top seam was

also found to be diamond-bearing. A little free gold has been found in this deposit.

The bottom layer of wash is made up of granite-boulders, from 2 to 4 inches in diameter. These range from subangular to perfectly waterworn, ellipsoidal stones. This band also contains quartz and tourmaline pebbles, and is about one foot in thickness. About one foot above this band, are a number of waterworn pebbles, decomposed to a soft bluish clay. These are mostly about an inch in diameter, but occasionally are of larger size.

Another occurrence of considerable interest is that known as the Round Mount. This is, as the name implies, a small, round hill, possessing a capping of basalt from 10 to 20 feet in thickness, and a series of river-gravels about 25 feet in depth. These gravels are isolated, and their position has given rise to much speculation. There is a ridge of granite separating them from the deposits at the Deep Shaft and the Streak of Luck. The internal evidence, as deduced from the slope of the bottom of the gravels from the edge to the centre of the channel, and also from the arrangement of the pebbles, indicates that the direction of the stream was from west to east at this point. On the northern side, and at a distance of about 100 yards, is another patch of river-gravels, also capped by basalt. The basalt is continuous between the two outcrops of gravel. At this place, the direction of the stream is to the southeast. The wash consists chiefly of quartz-pebbles from 4 mm. up to 4 cm. in diameter, with tourmaline, topaz, and garnet. A number of bluish boulders, from 2 cm. up to 20 cm. in length, resembling those of Soldier Hill, are also present. The isolated position of the Round Mount, and the fact that its river-gravels are at the same level as those of the Deep Shaft, have rendered the problem of determining the relation of the Round Mount, to the main Tertiary stream, a difficult one. The solution of the problem is to be found from the following facts. The trend of the lead at Soldier Hill is in a southerly direction, and, between this place and the Round Mount, occur the redistributed river-gravels at the football-ground. Again, the small patch of gravels, to the north of the Round Mount, is in the line of these occur-

rences. Moreover, the level of the gravels, at the Round Mount, is lower than that of the Soldier Hill deposits. It has also been pointed out that another mass of redistributed gravels occurs at the Koh-i-noor Mine, which lies between the Round Mount and the Star of the South Mine. There can, then, be little doubt that the part of the lead, flowing from Oakey Creek, continued through the Round Mount, and joined the main stream at a point between the Deep Shaft, and the Star of the South Mine. The position of the surface-gravels at the Sandy block, just west of the Round Mount, is doubtless due to the presence of a tributary joining the Oakey Creek branch at the Round Mount.

In addition to the occurrences just described, which have now been linked up into a continuous river-system, there are a few isolated patches of gravels which deserve a short description.

The Lone Star is the name given to a mine, which comprises two small basalt-capped hills overlying the granite and slate junction to the north of Cope's Creek. The gravels here underlie the basalt, but are at an elevation of 2,380 feet, which is considerably above that of the Tertiary system previously described. The lead at this point trends in a north-westerly direction. Mining is carried on chiefly for tinstone, but a few diamonds are almost invariably found in each washing. At about three miles to the north-west, another outcrop of gravels was noted; it is probable that these all belong to the same stream-course, and that this was a tributary to the main Copeton lead, which flowed north after crossing the present position of Cope's Creek. The general fall of the country was in this direction, as the Tertiary lead at Inverell is at an elevation of about 1,700 feet, and the level at Gragin, still further to the north-west, is about 1,400 feet.

Another isolated area of diamond-bearing gravels, is that situated at Staggy Creek, about 7 or 8 miles to the north-west of the Oakey Creek occurrence. The gravels are exposed at the surface, and no basalt is present. The deposit consists, for the greater part, of quartz-pebbles and boulders, ranging from 5 mm. to 20 cm. in diameter. A relatively large amount of tourmaline is present, and many of the larger quartz-boulders contain pencil-tour-

maline. Topaz and jasper are also to be found, and garnet is invariably present where the gravels are diamond-bearing. An iron-band, similar to that at Kirk's Hill and the Banca, was also noted. The whole diamond-bearing area is some 300 yards in length, and rather less than 100 yards in breadth. It's general direction is south-west. The gravels rest on a granite-surface, except at a spot near the centre of the area. Here, a small dolerite-neck, which is 60 yards long, by 10 to 15 yards wide, outcrops at the surface. The diamonds recovered were largest and most abundant in the vicinity of this neck. There are two shafts in the neck; and the dolerite has been examined, but no diamonds have been found in it. The deepest is 70 feet in depth, and the other is 30 feet deep. The dolerite was soft and decomposed for a considerable depth, but was hard and fairly fresh at the bottom of the deep shaft. Gold was found in washing for the diamonds, but only large flakes were recovered, as the method of diamond-washing could not save pieces less than 1·5 mm. in largest diameter. About 10,000 carats of diamonds are reported to have been won from this locality.

### v. Geology.

The geological features of the district include

(1) A series of clay-slates.
(2) A series of granites.
(3) Several basalt-flows.
(4) A number of basic dykes.

The clay-slates are the oldest rocks in this area. These have been mentioned in a former paper(3) on the district, and are not important from the point of view of this publication. The granites have been classified, in the same paper, into three types, the Acid granite, the Tingha granite, and the Oakey Creek granite. The granite which occurs at Copeton itself is intermediate in character to the first and second types, and was included, in the paper quoted, with the Tingha granite. A closer examination, however, has indicated that it is perhaps better classed with the Acid type. It is intermediate in chemical composition to the above types, resembling the Acid type more in chemical composition, and the Tingha type in physical characters.

The Acid granite has been shown to be intimately associated with the tin-deposits of the New England plateau. It is a coarse-grained granite, containing quartz-grains from 2 to 5 mm. in diameter, and tabular crystals of pink orthoclase up to as much as 15 cm. in length. A small amount of biotite is usually present, and the rock is not infrequently tourmaline-bearing. It thus has close affinities with the Alaskite of Spurr. The whole Tertiary system of diamond-bearing gravels at Copeton has this rock as its channel-base, with the exception of that part between the Oakey Creek and the Malacca mines, which rests upon the Oakey Creek granite. It is worthy of note that the portions of the Copeton leads which are diamond-bearing are nowhere far distant from the junction of the Acid granite with some other formation, of a greater geological age.

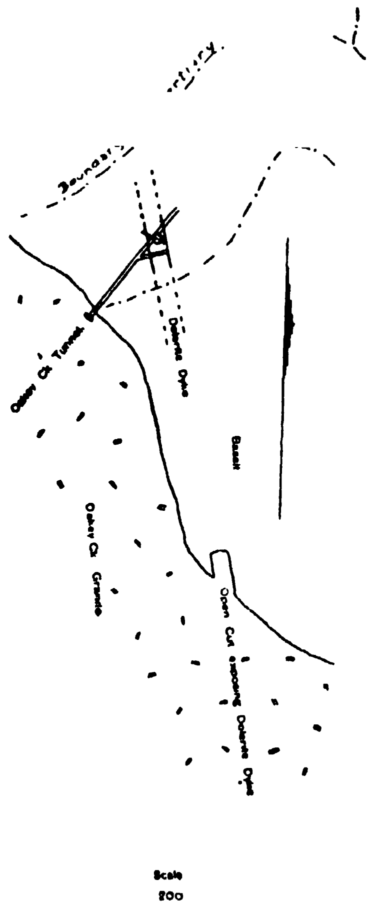
The Tingha granite has been shown to be older than the Acid granite. It is a hornblende-biotite type, containing tabular phenocrysts of plagioclase-felspar. It occurs only at the south-east portion of the area now under consideration. Text-fig. 3 shows the relationships of the series of rocks from Staggy Creek to Rider's Lead.

The Oakey Creek granite has been further investigated since it was last described, and has been found unique in the nature of its inclusions. The granite itself is very coarse, containing phenocrysts of plagioclase up to three inches in length. It is intersected by numerous tourmaline-bearing veins, in which this mineral occurs in long pencils up to three inches in length. The most striking feature, however, is the presence of a great number of inclusions. These are uniformly of one type, and consist of masses of dark-coloured rock containing phenocrysts of felspar similar to those in the granite. The inclusions are frequently more than a foot in diameter, and range in size down to small masses only an inch across. The shape of these is very variable. Some are spherical, others ellipsoidal, while others, again, are subangular. In all cases, the contact of these bodies with the granite is fairly sharp and well defined. The inclusions possess a dark base, consisting chiefly of biotite and quartz, in which are set pheno-

crysts of felspar and quartz. The felspars normally show signs of corrosion, and may be subangular or even ellipsoidal. A large inclusion, showing corroded felspars, is represented in Plate xc., fig.1.

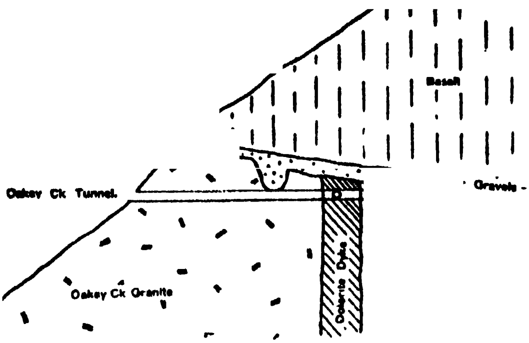
It is of interest to note that inclusions of an identical nature exist in the Acid granite at the Dutchman tin-lode, near Torington. This is about 70 miles to the north-east of the Copeton occurrence. As no such inclusions have been found in the Tingha granite, it is probable that the Oakey Creek granite is more closely related to the Acid granite than to this more basic type. As its morphological affinities, however, are more related to those of the Tingha granite, it is probably intermediate to these two types.

*Dykes.*—A number of felsite-dykes occur in the Copeton area, and these intersect both the Oakey Creek and Acid granites. None of these have yet been proved to be diamond-bearing, but some of them occur in positions which suggest that they may, at least, be regarded as possible sources of diamond-supply. In addition to these, there are two intrusions of dolerite known in the Oakey Creek granite, and both of these are undoubtedly intimately asso-



Text-fig.4.—Plan of the dolerite-dyke at Oakey Creek showing the spot (marked by a circle) where the diamond was found in matrix.

ciated with diamond-bearing gravels. These have been mentioned in connection with the Tertiary deposits at Oakey and Staggy Creeks. A petrological description of the rocks, and an analysis from each locality, are given under the section on Petrology. It is evident that the rocks are very similar in chemical and physical characters. The analyses show that they differ considerably, in chemical composition, from the peridotite of the South African mines. The Oakey Creek occurrence (Plate xci., fig. 1) deserves special mention. The plan (Text-fig. 4) illustrates the position




Text-fig.5.—Section illustrating the dolerite-dyke at Oakey Creek.

and known extent of the dolerite-mass at Oakey Creek. The section (Text-fig. 5) shows the relationships of the dyke, granite, river-gravels, and basalt. The linear development and the plane slickensided wall, showing in one of the drives, enable the mass to be classed as a dyke. It is 26 feet wide in the main drive, and is a considerable width at a distance of 500 feet to the south of this drive. The width here cannot yet be determined, as the open cut has disclosed only one boundary of the dyke-mass. There is very clear evidence that this dyke was older than the river gravels overlying it, as an exposure in the easterly drive shows the contact of these. Moreover, decomposed boulders of the dyke-mass are abundant in the river-gravels.

The dyke intrudes the Oakey Creek granite, and the junction is sharp and well defined. Though there is no marginal differentia-

tion in the dolerite, it is common to find in it fragments of quartz, which have undoubtedly been derived from the granite. The microscopic examination reveals the presence of a very small amount of free quartz, but this appears to have crystallised from solution, and not to be of an included nature.

The small neck at Staggy Creek, is composed of practically the same rock. As the localities are distant about four miles, it is probable that the magma, from which the rocks were formed, was of some considerable extent. This neck also intrudes the granite-mass, and no sedimentary rocks occur within some 4 or 5 miles of either occurrence. It must be noted that, in each case, diamond-bearing river-gravels of later age have been found overlying the dolerite-masses.

Not only is this so, but, in the case of one of these, it has been amply demonstrated that a diamond was found fast embedded in the dolerite-matrix. The specimen has been preserved, and has been shown to many eminent geologists by Prof. T. W. E. David, who writes* as follows: -"At the meeting of the British Association at York, England, as well as that of the International Geological Congress of Mexico last September, this specimen was most critically examined by the chief scientific authorities on diamonds in the world, and all were satisfied as to the absolute genuineness of the discovery, and considered it of the highest possible scientific interest." A second diamond was also exhibited with the one embedded in matrix. This was stated to have been found free in the heap of decomposed dolerite. It was agreed, by scientific observers, that this was even better evidence of the genuineness of the discovery, from the fact that the diamond was pitted, and that the pits were filled with finely crystallised dolerite, evidently *in situ*.

Having examined both the above-mentioned specimens, and the spot where they were found, I also feel quite convinced of the genuineness of the discovery.

Active interest was aroused in 1912, and about 100 tons of the dolerite were mined and exposed to the weather. Shortly

* Prof. T. W. E. David, Sydney Morning Herald, 19th and 26th January, 1907.

before my visit, in January, 1913, some nine tons of this were screened and washed. Two diamonds were shown to me, which were reported to have been recovered from this test. About three tons more were washed in my presence, but no diamonds were recovered.

It thus appears that, quite apart from the fact that diamonds have been found in the dolerite, the evidence points to the dykes as the probable source of the diamond-supply. From the great variety, both in size and character, of the diamonds from different parts of the leads, it is probable that the diamonds have been derived from a great number of such dykes or necks. These are, probably, like the Oakey Creek occurrence, still hidden by the recent basalt-flows.

## vi. Petrology.

### *The Oakey Creek Granite.*

Crystallinity: holocrystalline.

Grainsize: *relative*, porphyritic; *absolute*, smaller crystals from 3 to 6 mm.; phenocrysts up to 8 cm.

Fabric granitoid; also graphic intergrowth of quartz and orthoclase in some instances.

Minerals in order of decreasing abundance: quartz, orthoclase, albite, biotite, microcline, muscovite, magnetite, apatite, and fluorite.

Secondary minerals: kaolin and chlorite.

The felspars have crystallised out in two generations; the older ones are idiomorphic, zoned, and fairly free from decomposition, while the opposite characteristics mark the later felspars. These remarks apply to both the orthoclase and the albite. The biotite is a dark variety, its pleochroism varying from yellowish-brown to very dark brown.

A small amount of microcline is present in subidiomorphic crystals.

The muscovite is rather rare, and is mostly included in the orthoclase. It oppears to have been corroded by the magma subsequently to its complete crystallisation.

The apatite possesses its characteristic, prismatic habit.

One or two very small allotriomorphic grains of fluorite were observed in one slide of this rock.

*Quartz-dolerite.* *Loc.*—Oakey Creek.

Crystallinity: holocrystalline.

Grainsize: evengrained, the typical crystals varying from 2 to 6 mm.

Fabric: a network of plagioclase felspars with subordinate augite. The interstitial material is a brown chlorite, with a few decomposed biotite crystals.

The chief minerals, in descending order of abundance, are oligoclase, labradorite, augite, chlorite, magnetite, biotite, and quartz.

A little secondary hornblende is present, and the felspars, though fairly fresh, on the whole, show some signs of kaolinisation along some of the major cleavage-cracks. The felspars vary from oligoclase to basic plagioclase. The most basic felspar-crystals, as determined by the method of Michel Levy, are labradorites of the composition $Ab_2An_3$. Many of the crystals are strongly zoned, and the different zones vary widely in composition. The outer edge is often oligoclase, and the central area anorthite. The augite, which is very fresh, is an almost colourless variety, with a faint colour suggesting that it is titanium-bearing. It is intermediate in composition between diopside and true augite.

The most interesting, and, at the same time, most puzzling feature, is the presence of the brown, chloritic, interstitial material, and also idiomorphic quartz-crystals The chlorite is often arranged in a manner which suggests that it has been derived from an augite, which was originally involved in an ophitic structure with the plagioclase. The structure has been variously interpreted by different observers. Professor Bonney and Professor David have suggested that the chlorite is a secondary product derived from a primary hornblende. Dr. A. Thompson has considered its derivation from augite unlikely, because of the freshness of the augite associated with the felspar in the rock. He has suggested that the chlorite may represent a devitrified glass.

There is, however, a constant association of idiomorphic quartz-crystals with the chlorite, which has not, so far, been recorded. In Plate xci., fig.3, this arrangement may be seen. The small,

clear, hexagonal crystal, in the darker mass surrounding it, is a quartz-crystal in chlorite. This structure occurs only on a small scale, but it is very characteristic of the whole rock. In places, the quartz has been partly resorbed, and the chlorite-fibres penetrate into it. Again, it is not uncommon to find a modified graphic intergrowth of chlorite and quartz. From this, it would seem that the quartz crystallised rather before the chlorite, on the whole, but that, in certain parts, the crystallisation was simultaneous.

These relations of the quartz and chlorite seem opposed to the derivation of these minerals from a primary mineral, such as hornblende or augite, or even from a glassy base. On the other hand, much of the magnetite and ilmenite appears to be of a secondary nature. The opaque crystals are, in places, moulded about the felspars and the augite. A considerable amount of the iron-ores appears to be associated with the chloritic material.

A number of acicular crystals are present, which are idiomorphic to the felspar. These appear to be tremolite. They do not appear to bear any definite relation to the chloritic material.

Leucoxene is present, bordering the ilmenite.

*Quartz-dolerite.* *Loc.*—Staggy Creek.

Crystallinity: holocrystalline.

Grainsize: relatively evengrained, the normal crystals varying from 2 to 5 mm. in diameter.

Fabric: a network of plagioclase felspars, with grains of nearly colourless augite. The augite is very subordinate in amount, being distinctly less abundant than in the Oakey Creek dolerite. There also occurs a considerable amount of interstitial chlorite, as in the Oakey Creek dolerite.

The chief minerals, in descending order of abundance, are oligoclase, labradorite, augite, chlorite, ilmenite, magnetite, quartz, and biotite.

The felspars are very similar to those of the Oakey Creek dolerite, but the sample was not so fresh in this rock, and the felspars, consequently, are more kaolinised. The most basic felspar observed was labradorite of the composition $Ab_3An_7$, and, the most acid, an albite-oligoclase. Zoning occurs in the felspars,

the composition of the zones varying from albite-oligoclase at the margin, to basic plagioclase in the centre of the crystals.

The augite, which is slightly more coloured than that of the Oakey Creek dolerite, is much less abundant than in that rock. The grains, moreover, are much smaller in size.

The chlorite, which is also less abundant than in the Oakey Creek dolerite, has the same characteristic relation to the felspars, and, moreover, the same strange property of including idiomorphic quartz-crystals. These quartz-crystals are, however, less abundant in this rock. The same problem as to the origin of the chlorite, therefore, exists.

Ilmenite is more abundant than in the Oakey Creek dolerite, as also is leucoxene.

ANALYSES AND MOLECULAR RATIOS.

i. Oakey Creek quartz-dolerite.
ii. Staggy Creek quartz-dolerite.
iii. Hard rock (blue ground) De Beer's Mine, Kimberley.
iA. Molecular ratios of i.
iiA. Molecular ratios of ii.

| | i. | ii. | iii. | iA. | iiA. |
|---|---|---|---|---|---|
| $SiO_2$ ... | 50·43 | 51·16 | 49·50 | 841 | 853 |
| $Al_2O_3$ ... | 14·72 | 17·98 | 18·40 | 144 | 176 |
| $Fe_2O_3$ ... | 2·90 | 2·85 | 13·10 | 18 | 18 |
| FeO ... | 4·59 | 4·09 | | 64 | 57 |
| MgO ... | 6·67 | 4·10 | 5·25 | 167 | 102 |
| CaO ... | 7·13 | 7·30 | 2·24 | 128 | 130 |
| $Na_2O$ ... | 2·47 | 3·92 | 4·65 | 40 | 63 |
| $K_2O$ ... | 1·23 | 1·61 | 1·48 | 13 | 17 |
| $H_2O-$ ... | 3·49 | 2·51 | 5·23 | 193 | 139 |
| $H_2O+$ ... | 3·82 | 2·32 | | 212 | 129 |
| $CO_2$ ... | 1·67 | 1·03 | | 38 | 23 |
| $TiO_2$ ... | 0·82 | 1·27 | — | 10 | 16 |
| $P_2O_5$ ... | 0·22 | none | — | 1 | none |
| MnO ... | 0·03 | — | — | — | — |
| $Cr_2O_3$ ... | 0·02 | — | — | — | — |
| $V_2O_3$ ... | 0·03 | — | — | — | — |
| $SO_3$ ... | 0·01 | — | — | — | — |
| | 100·25 | 100·14 | 99·85 | — | — |

Norm of the Oakey Creek quartz-dolerite.

| | |
|---|---|
| Quartz | 9·36 |
| Orthoclase | 7·21 |
| Albite | 20·96 |
| Anorthite | 24·20 |
| Hypersthene | 20·14 |
| Calcite | 3·80 |
| Corundum | 0·30 |
| Magnetite | 4·18 |
| Apatite | 0·31 |
| Ilmenite | 1·52 |
| Water | 7·31 |
| | 99·29 |

Norm of the Staggy Creek quartz-dolerite.

| | |
|---|---|
| Quartz | 2·70 |
| Orthoclase | 9·62 |
| Albite | 33·01 |
| Anorthite | 26·69 |
| Diopside | 14·52 |
| Magnetite | 4·16 |
| Ilmenite | 2·44 |
| Calcite | 2·30 |
| Water | 4·83 |
| | 100·27 |

Both the microscopical examination and the analyses of the Oakey Creek and Staggy Creek rocks indicate their close relationship. The association of each of them with diamonds in Tertiary river-gravels is another harmonic relation. In view of the evidence for the occurrence of diamonds in the Oakey Creek dolerite, there can be little doubt that the Staggy Creek rock is also diamond-bearing.

The diamonds in South Africa seem to be found associated with a more basic rock—a peridotite in which the silica-percentage is often below 40 %, and the percentage of magnesia above 25 %. There cannot, therefore, be said to be a close relationship between the South African peridotites and the Copeton dolerites.

It is interesting to note, however, that rocks very similar to the Copeton dolerites have been found in the peridotite-necks of South Africa.

Analysis numbered iii., is of a "hard rock" from the blue ground of De Beer's mine at Kimberley. This rock closely resembles the Staggy Creek dolerite, the chief difference being that the South African rock possesses about 6 % more of the iron oxides, and about 5 % less lime than the New South Wales variety.

In addition to this rock, I have examined microscopically an olivine-dolerite stated to be from the Kimberley pipe, which, apart from its relatively small percentage of olivine and absence of quartz, is not unlike the Oakey Creek dolerite.

Although these two South African rocks do not appear to represent the type-rocks of the South African diamond-bearing necks, it is interesting to note that they do occur associated with the diamond-deposits.

## vii. Summary.

The first discovery of diamonds in the Copeton district was made in 1872 or 1873, simultaneously with the discovery of tinstone in the district. The diamonds were first found in alluvial workings, but these had been derived from the denudation of basalt-capped leads. These leads are probably of late Tertiary age. The physiographic investigation shows that the present drainage-system of the district trends to the west, but the pre-basaltic drainage was in a northerly direction. The original course of the Gwydir was northwards from Copeton to Inverell, and it then received the Macintyre as a tributary stream. The present course of the Gwydir has followed the eastern and northern edges of a block-fault. The western boundary of this block-fault has been examined by W. N. Benson, and we have agreed to name the sunken area "Keera," from a Station of that name situated in the area of subsidence. The basalts and river-gravels (which are after Anderson) shown on the accompanying map, illustrate the Tertiary river-system in its relation to the present-day drainage.

The material filling the beds of the Tertiary stream-channels is grouped under four heads: (1) the wash; (2) the drifts; (3) clay-deposits; (4) lignite. There is no locality in which all four are developed, and, as a rule, only the first two are present. The wash is the term applied to the coarser bands of material. This has usually collected on the base of the stream-channel, and contains the heavier minerals. Consequently, it is essentially the diamond-bearing stratum of the deposit. The wash seldom exceeds one foot in thickness. The drifts are aggregates of loose and rather fine, sandy material, usually stained red from the leaching of iron oxide from the overlying basalt. These deposits attain, in several places, a thickness of 20-25 feet. The clay-deposits consist of kaolin derived from the decomposition of the felspars in the granite, and have been deposited under lacustrine conditions. Lignite occurs rarely, and overlies the drifts. It does not appear to have been much affected by the overlying basalt.

The geology of the district is represented on the accompanying map. It will be seen that there are present (1) slates; (2) granite; (3) dykes; (4) basalt.

The slates cover a small area, and are unimportant in connection with this paper. The granite is represented by three types —the Acid, Tingha, and Oakey Creek granites. The first is the younger, and the last is probably intermediate in age to the first two types. The dykes are of two varieties—(*a*) fine-grained felsites; (*b*) dolerites. These dykes have intruded the granites, but are older than the basalts and the basalt-capped leads.

The basalts are the youngest rocks in the district. These overlie the Tertiary gravels, and obviously cannot have been a source of diamond-supply. It is also shown that it is highly improbable that the diamonds can have been derived from either the slate or the granites. This points to the dykes as the probable origin of the diamond-supply.

This "proof by exhaustion" evidence in favour of the dyke-material as the diamond-matrix has been confirmed by the discovery of a diamond in the dolerite-dyke at Oakey Creek. A Tertiary stream-channel has crossed this dyke, and diamonds were found in the gravels adjacent to the dyke on the down-

stream side of it. A similar dyke, or small neck, of an almost identical rock was found at Staggy Creek, some 4 miles north-west of this occurrence. In this case, also, diamonds were found in the gravels overlying the dolerite-mass. The occurrence of two such masses of dolerite, associated with the diamond in this area, gives strong grounds for supposing that the whole of the diamonds of the Copeton field have been derived from similar sources. The two known dolerite-masses are so situated that they cannot have supplied more than a portion of the Tertiary deposits.

It is probable that most of the sources of supply of the diamonds are now concealed by the later basalt-flows, in the same way as the Oakey Creek occurrence.

In conclusion, I take the opportunity of here thanking those who have assisted me in this work. To the miners of Copeton, and pre eminently to Mr. A. R. Pike, my best thanks are due for kind assistance in field-work. I am also indebted to Professor David, for help and encouragement during the preparation of this paper; and to Mr. A. Pain, for some assistance in rock-analysis.

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## EXPLANATION OF PLATES XC.-XCII.

### Plate xc.

Fig. 1.—Inclusion in the Oakey Creek granite, near its junction with Cope's Creek, showing large phenocrysts of felspar set in a groundmass of felspar and biotite.

Fig. 2.—View of Copeton from Soldier Hill, looking east. The foot-hills in the distance mark the trend of the Tertiary lead from the Deep Shaft to the Old Farm.

### Plate xci.

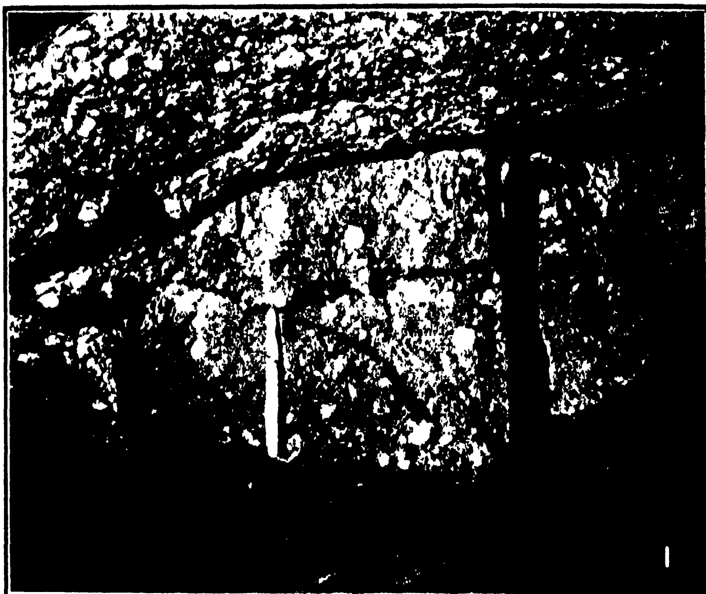
Fig. 1.—Oakey Creek, showing the mouth of the tunnel in which a diamond was found in the matrix.

Fig. 2.—The bed of Cope's Creek, near its junction with the Gwydir, showing remarkable triangular depressions left after a small flood.

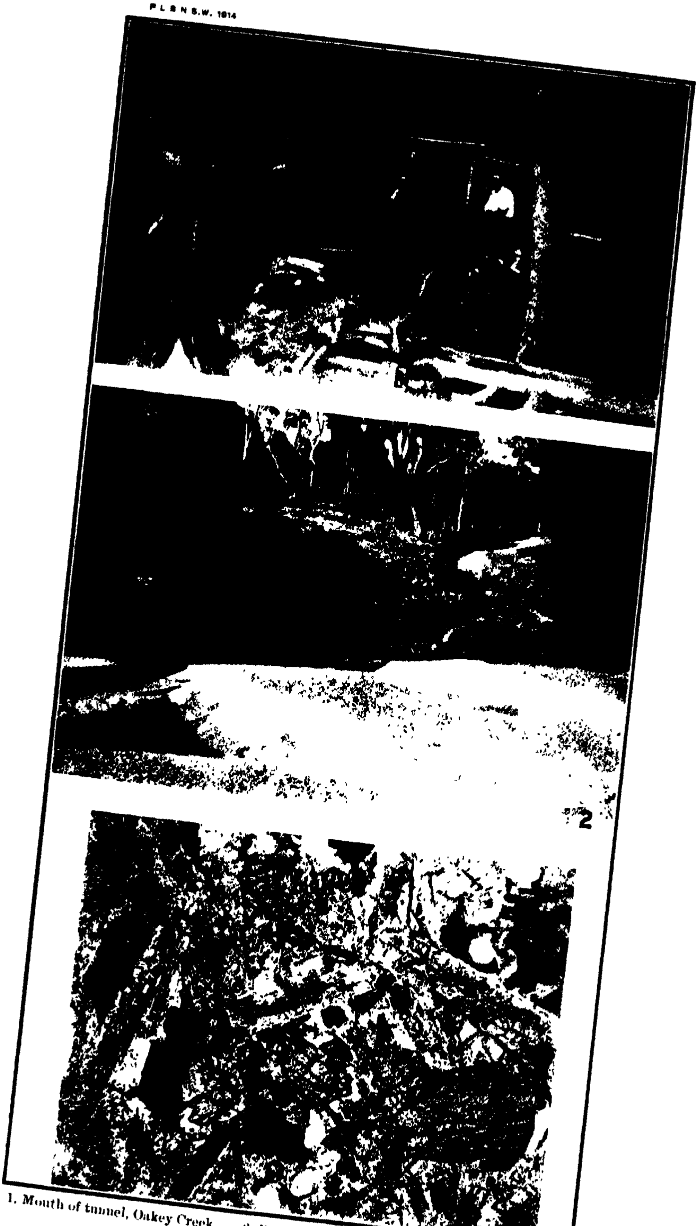
Fig. 3.—The Oakey Creek dolerite, showing felspars, augite, ilmenite, and chlorite. Note the small hexagonal section of quartz embedded in chlorite.

### Plate xcii.

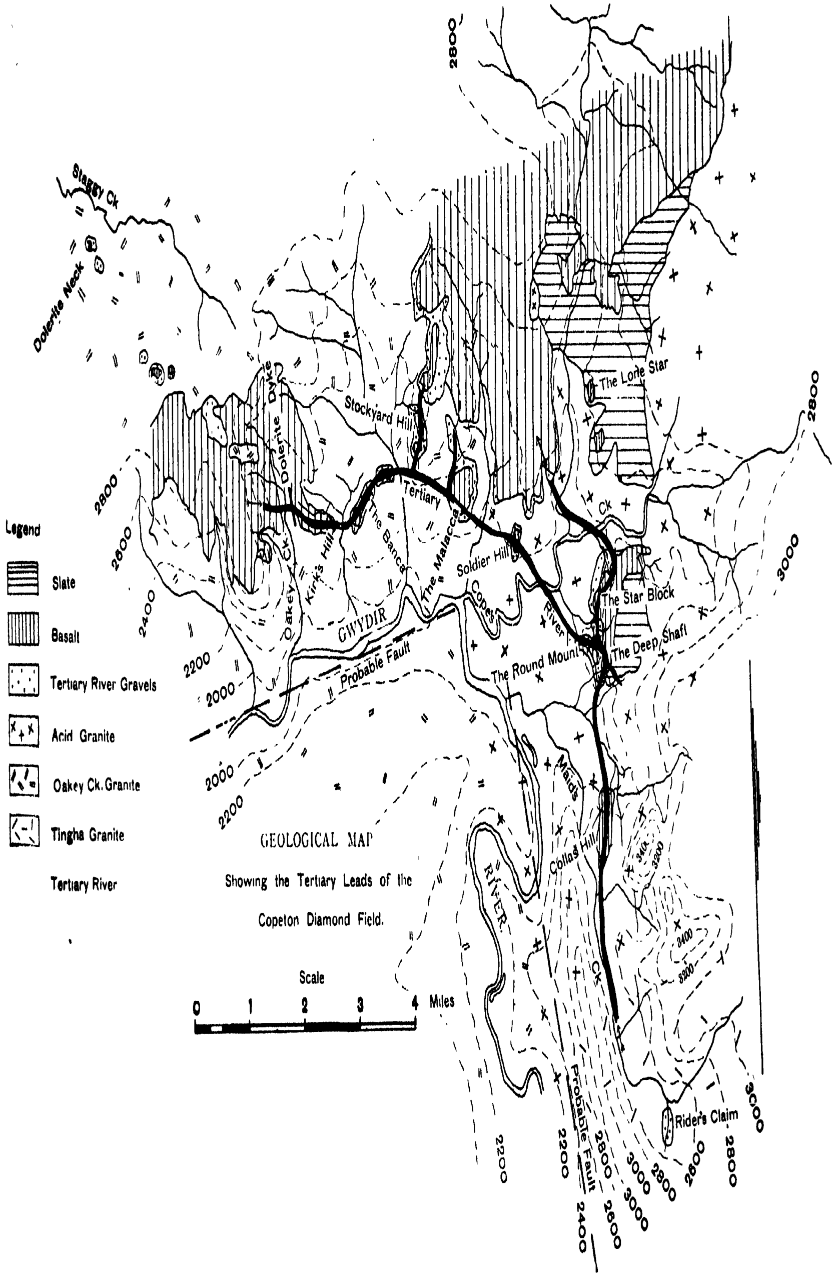
Geological Map showing the Tertiary Leads of the Copeton Diamond-field.



1. Inclusion in Oakey Creek granite. 2. View of Copeton from Soldier Hill, looking east.




1. Mouth of tunnel, Oakey Creek. 2. Bed of Cope's Creek. 3. Oakey Creek dolerite.




GEOLOGICAL MAP

Showing the Tertiary Leads of the Copeton Diamond Field.

# SOME GEO-PHYSICAL OBSERVATIONS AT BURRINJUCK.

# SOME GEO-PHYSICAL OBSERVATIONS AT BURRINJUCK.

By LEO A. COTTON, B.A., B.Sc.,
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With Plate LXII, and Three Text-figures

[*Read before the Royal Society of N. S. Wales, December 1, 1915.*]

THE problems relating to the strength of the earth's crust present an attractive field of investigation alike to the mathematician, the physicist and the geologist. Such investigators as Fisher, Darwin and Love have given attention to the mathematical aspects of the question. In the realm of physics such men as Airy, Hecker and Hayford have respectively examined the problems from the standpoints of astronomy, seismology and geodesy. Among geologists, such names as Gilbert, Chamberlin and Barrell are associated with these problems.

In this communication it is desired to present a brief preliminary account of a new experimental line of investigation in this branch of science.

The State Government of New South Wales have undertaken a large irrigation scheme,[1] the reservoir for which is being constructed on the Murrumbidgee River at Burrinjuck. The dam is to have a maximum height of 236 feet, and the water to be stored is estimated at 33,000,000,000 cubic feet, a greater volume than the water contained in Sydney Harbour. The impounding of such a large mass of water, having such a great depth, will impose a certain strain on the earth's crust.

[1] For a brief account of this work see Handbook for New South Wales, published for members of the British Association for the Advancement of Science, 1914, pages 146, 147

The opportunity which this engineering work offers for the investigation of the strength of the earth's crust was first realised by Dr. W. G. Woolnough, who was then a lecturer in Geology at the University of Sydney. He suggested that some suitable instrument be installed at the reservoir in order to ascertain whether any deflection of the earth's crust would take place under the water load; and he undertook to carry out the investigation. The Australasian Association for the Advancement of Science granted financial assistance to further the project. The subsequent appointment of Dr. Woolnough to the Chair of Geology at Perth, rendered it impossible for him to proceed with the work. Some time later, the Rev. Father Pigot, S.J., suggested to Professor David that certain pendulums which he had seen during a visit to Europe would be suitable for the investigation, and it was decided to write to Geheimrat Helmert requesting the loan of these valuable instruments. Helmert with the co-operation of Hecker and Wolf most generously arranged to lend three instruments for this investigation, which was planned to extend over a period of three years. The pendulums were shipped to the care of Professor David free of charge, and were received a few months before the outbreak of war. It is a matter for the most profound regret that the spirit of universal scientific brotherhood so well exemplified by this most generous loan has since been so conspicuously absent from the counsels of the German Government.

Two of the pendulums lent were used by Hecker (Potsdam) and Schweydar (Heidelberg) in their classical investigations on the earth tides. These instruments are of the Rebeur-Ehlert type. The third pendulum was constructed to Hecker's design and is of the Zöllner suspension type.

The care of these valuable instruments brought with it a high degree of responsibility for their safe housing and

proper installation. It was decided that if possible they should be placed in tunnels in the steep hillsides as close as practicable to the high water level of the Burrinjuck reservoir. The steep slope of the hills (about 30°) would enable the instruments to be established at a sufficient depth from the surface to minimise or eliminate the effect of surface temperature changes. The State Government generously granted the aid necessary to the preparation of these tunnels. The greatest thanks are due to the late Commissioner for Irrigation, Mr. L. A. B. Wade, for his personal interest and help in connection with this work, and also to Mr. Dare, the present Acting Commissioner, at that time Chief Engineer to the Irrigation Commission. The tunnels were driven under the supervision of the resident engineer at Burrinjuck, Mr. D. F. Campbell. This gentleman has rendered the most invaluable service both in connection with the installation and the subsequent maintenance of the instruments. It is due to his enthusiastic devotion and interest, that in spite of many difficulties, the records of the present year have yielded such satisfactory results. Thanks are also due to Mr. Goodwin for his valuable services in changing the records.

The selection of the sites for the tunnels and the installation of the instruments were carried out jointly by Professor David, Father Pigot, Mr. D. F. Campbell and the writer. The sites chosen are shown on the accompanying map (Plate LXII). The tunnels are placed from twenty to forty feet above high water level and are from sixty to eighty feet in length. Each tunnel is divided transversely into three compartments. The pendulums are housed in the compartment remote from the entrance, the lamp and photographic recording apparatus in the centre compartment, while the outer compartment serves as a storage room for accessories and as an additional protection to the

photographic records[1] in the centre chamber. This three-fold division also minimises the risk of air temperature changes affecting the instruments during visits necessary for changing the records.

Both the pendulums and the recording apparatus are mounted on solid concrete piers and are roofed over to afford a protection against water seepage and small falls of earth.

The recording apparatus[2] for two of the instruments had to be made in Sydney and the expenditure which this work necessitated was met by a further grant from the Australasian Association for the Advancement of Science. A full account of the instruments and their installation will be given in a later paper.

The first of the instruments (the Heidelburg pendulum established at Dale's Tunnel), was installed by Father Pigot in May 1914, and all three instruments were recording in October of that year. The records, however, have only been yielding satisfactory results since February 1915. Although the records obtained since that date are not sufficiently extensive to be used as a basis for a quantitative investigation, there are certain results of a qualitative nature which are of extreme interest to both geologists and geodesists. As it is proposed to continue the observations for a further period of two years before attempting a quantitative statement, the writer was requested to make such a preliminary statement as is now possible for the information of those who are interested in this research.

As a preliminary step towards the investigation it would clearly have been desirable to ascertain as far as possible,

[1] Harrington's Limited are providing the photographic materials, and are kindly giving special attention to ensure the greatest possible speed for the paper.

[2] This recording apparatus was made by J. Cruikshank, Scientific Instrument Maker, No. 9 Nicholson-street, Wooloomooloo.

the normal stability of the earth's crust at Burrinjuck. There are two methods of attacking this problem.

The first is by obtaining a set of standard readings with the pendulums before any water load is imposed on the area.

The second method is to apply geological tests as to the stability of the earth's crust.

It has unfortunately not been possible to rigidly carry out the preliminary investigation by the first method. Owing, however, to a period of drought, and to the necessarily slow growth of the dam, the water load had not exceeded about one-sixteenth of the total load before the instruments were established. Moreover this load was maintained fairly constantly for about nine months since the first records were obtained. It is hoped that when the results are worked out, that this period will provide a sufficient test of the normal stability of the earth's crust in this area.

The second method will be investigated fully in a later paper but may be briefly outlined here.

A consideration of the topography and structural geology of the district is necessary for the solution of the problem. The Burrinjuck area is situated on a block faulted tableland, which is deeply entrenched by the Murrumbidgee at Burrinjuck. The rocks at Burrinjuck are of Devonian age, are strongly folded, and consist of slates and limestones into which are intruded granite, porphyrite and basalt. An accountof the broad geological features of the reservoir area has been given by Harper.[1] The faulting is comparatively recent, and slight earthquakes have from time to time been felt in the south-eastern part of New South Wales. The most marked of these of recent years occurred in the Cooma

[1] L. F. Harper. The Geology of the Murrumbidgee District near Yass. Records Geological Survey New South Wales, Vol. IX, part 1.

and Bega area, on 18th January, 1912, at 6·9 a.m. This earthquake was felt over an area having a diameter of about 100 miles, and was recorded at the Riverview Observatory. These earthquakes indicate that crustal equilibrium has not yet been attained in this area.

### The Records.

The records of each instrument from 22nd February 1915 to the 19th October of the same year are represented graphically in the accompanying diagrams. The water level is represented in each case by a curve, the ordinates of which are proportional to the actual water levels recorded at the dam.

In the case of each pendulum boom the ordinates are proportional to the actual displacements of the booms as recorded on the photographic records. The actual deflections of the vertical for each instrument for the period commencing 22nd February and ending 21st October 1915 are represented on the accompanying map (Plate LXII).

In the case of the No. 1 Pendulum (the Heidelberg pendulum established at Dale's tunnel), there was relatively little movement of the booms while the water level was slowly sinking, but both booms manifested considerable activity when the water load was increased. The sense of the movement is in the direction represented by an arrow on the accompanying map.

In the case of No. 2 Pendulum (the Strassburg Zöllner-suspension instrument, established at the Weighbridge tunnel) the deflections of the vertical are also represented on the map. The variations in the water level, however, do not exert any marked corresponding influence on the movements of the booms. This instrument is situated near the dam, and is therefore subjected to the maximum stress so far as depth of water is concerned; and hence a small rise or fall of the water level would represent only a

relatively small fraction of the total water load. The variations in water level might thus be expected to affect the booms less than in the case of either of the other pendulums.

In the case of No. 3 Pendulum (the Potsdam Pendulum established at the River Tunnel), both booms are deflected in a most marked manner. In this case also the amount and direction of the deflection of the vertical is represented on the map. This pendulum is twelve miles above the dam, and the water load is not great, being represented by a depth of about twenty-two feet of water at the commencement of the records. Small variations in the water level therefore represent large relative changes in the stresses imposed. This is consistent with the nature of the curves.

Thus in the case of each instrument there is a degree of correspondence between the movement of the pendulum booms and the variation in the water load; and this correspondence is so marked as to render a causal connection in a high degree probable.

There are at least four types of earth movements which are being recorded by the pendulums. These are

1. Earthtides. 3. Fault movements.
2. Earthquakes. 4. Slow deflections of the vertical.

*The Earthtides.*—As two of the pendulums were previously used for the detection of the earthtides in Europe, it was to be expected that they would record this phenomenon at their present stations. This expectation has been fulfilled.

As Burrinjuck is situated 125 miles due west from the coast of New South Wales at Jervis Bay, it is possible that the records may be slightly influenced by the load of the oceanic tides. It will be of great interest to compare the records of these instruments with those from the Standard Earthtide Station at Cobar. This station forms part of the

world scheme initiated by Hecker for the International Geodetic Association. It was established by Father Pigot at Cobar a short time before he commenced the installation at Burrinjuck. The Cobar instrument is of the Zöllner suspension type and was set up in a disused mining drive at a depth of 450 feet from the surface. As Cobar is about 360 miles from the coast it is anticipated that the effect of the oceanic tides will be quite negligible at this station. If the oceanic tides do exert a measurable effect at Burrinjuck, a comparison of the records with those of Cobar should provide a means of ascertaining the magitude of this effect. If, on the other hand, the oceanic tides exert no appreciable influence at Burrinjuck, the records will be of value in supplementing those at Cobar. Unfortunately the Cobar mine has been closed during the greater part of the past year, so that simultaneous records from Cobar and Burrinjuck are not yet available. The mine is, however, now being re-opened, and the installation of the pendulum will be shortly re-established by Father Pigot.

*Earthquakes* are readily recorded by all the pendulums. The periods of the booms in the different instruments vary from about eighteen to twenty-six seconds for a relatively small arc of oscillation. These records have of course no time value, as the travel of the photographic paper is only from one to three centimetres per hour; nor are the amplitudes of much value as the pendulums are undamped. Nevertheless the earthquakes are of importance in their possible relation to faulting. Earthquakes of large amplitude have on several occasions been accompanied by sudden displacements of the zero of the booms under conditions which sometimes suggest fault movements rather than instrumental errors. As a rule the earthquakes are not accompanied by displacement of the zero position of the booms.

*Fault movements* are represented on the records by relatively rapid movements of the booms. In most cases the movement occupies only a few hours, resulting in a permanent displacement of the zero position of both booms, these faults are generally unaccompanied by any earthquake shocks. They sometimes occur in the same sense as the preceding slow movements of the pendulum booms and at other times in the opposite direction. The position of the fault plane and the direction of the downthrow with regard to the position of the instrument no doubt determines this relation. It is hoped that the chief lines of fracture may be located by observations from all three instruments.

It is, however, in the slow deflections of the vertical that the main interest of the investigation lies. These movements may be related chiefly to the water loads or may be due to other causes, but it seems almost certain that the former cause is in operation. More light will no doubt be cast upon the problem by further investigation.

### Interpretation of the Records.

It is as yet premature to offer definite conclusions, but there are certain suggestions that may be considered. Is it possible that the deflections of the vertical, which are undoubtedly taking place at Burrinjuck, are due to isostatic adjustment?

In this connection we have involved the question of local versus regional isostacy. Barrell's investigations of the strength of the earth's crust are strongly opposed to the possibility of such a relatively small mass as the water content of the Burrinjuck Reservoir having any isostatic effect. On the other hand Hayford and Bowie consider that isostatic adjustment may affect areas as small as one square mile in extent.

Is it possible that both these views may be reconciled?

In an area such as that of Burrinjuck, where the earth's crust has been proved to be fractured by many large faults, there is not that strength of the crust postulated in Barrell's investigations. Even small areas are divided in blocks by fault planes, and it is conceivable that each small area may work into a position of isostatic adjustment more or less independently of its neighbour. Conditions such as these would favour Hayford's limits for isostatic compensation in areas of this type.

If isostatic adjustment is not responsible for the deflections observed, are these to be explained by the elasticity of the earth's crust?

The instruments are certainly sensitive to small loads close to their bases of support. After spending about twelve or fifteen hours within a distance of from three to fifteen feet of the pendulums, it was found that the records always showed a gradual recovery from the strain imposed on the rock floor by one's weight. It may be that the movements of the booms are to be attributed to the water load operating in the same way. It is hoped that a quantitative examination of an extended series of records will enable the nature of the deflections of the vertical to be ascertained.

In the meantime it is certainly a matter of interest that such deflections are taking place, and that these appear to be related to the water load.

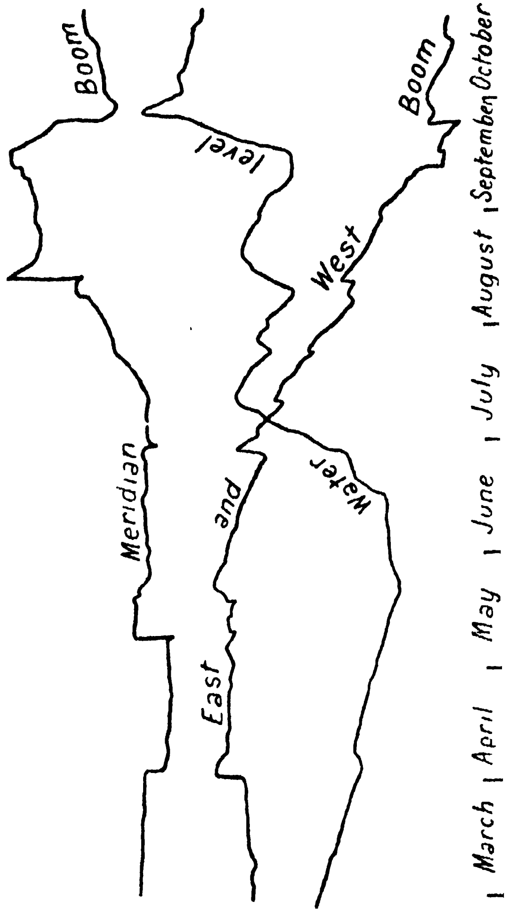
In conclusion, I would desire to express my great indebtedness to both Professor David and Father Pigot for constant advice and assistance in connection with this work; to the latter especially for his advice and guidance in completing the installations which he himself commenced but was unable to complete owing to his visit to Europe; and for his most generous help in the preparation of this paper.

**Explanation of Figures and Plate LXII.**

Figure 1.—Pendulum No. 1 (Heidelberg Pendulum).

The deflections of the vertical registered by both booms are represented by the changes in the ordinates of the

Fig.




curves, which are drawn to a scale on which one centimetre represents about 1·48 seconds of arc. The amount of

deflection prior to the 22nd February is not known. In the case of the meridian boom an increase in the ordinate represents a deflection of the boom towards the east. In the case of the east and west boom a decrease in the ordinate corresponds to a deflection of the boom to the north. The curve representing the water level is drawn to a scale on which one centimetre represents twenty feet of water. The actual water level on 22nd February was fifty-two feet above the river bed at the site of this pendulum.

The abscissæ represent the times corresponding to the ordinates of the curves and are drawn to a scale of twenty days to one centimetre.

Figure 2.—Pendulum No. 2 (Strassburg Pendulum).

The deflections of the vertical registered by both booms are represented by the changes in the ordinates of the curves. These are drawn to a scale on which one centimetre represents about 0·64 seconds of arc. The amount of the deflection prior to 22nd February 1915 is not known. In the case of the meridian boom an increase in the ordinate represents a deflection of the boom towards the east. In the case of the east and west boom a decrease in the ordinate represents a deflection towards the south. The curve representing the water level is drawn to a scale on which one centimetre measures twenty feet of water. An increase in the ordinate corresponds to a rise of the water level. The actual water level at the 22nd of February, 1915, was eighty feet above the river bed at the site of this pendulum. The abscissæ of all the curves represent the times corresponding to the ordinates, and are drawn to a scale of twenty days to one centimetre.

Fig.

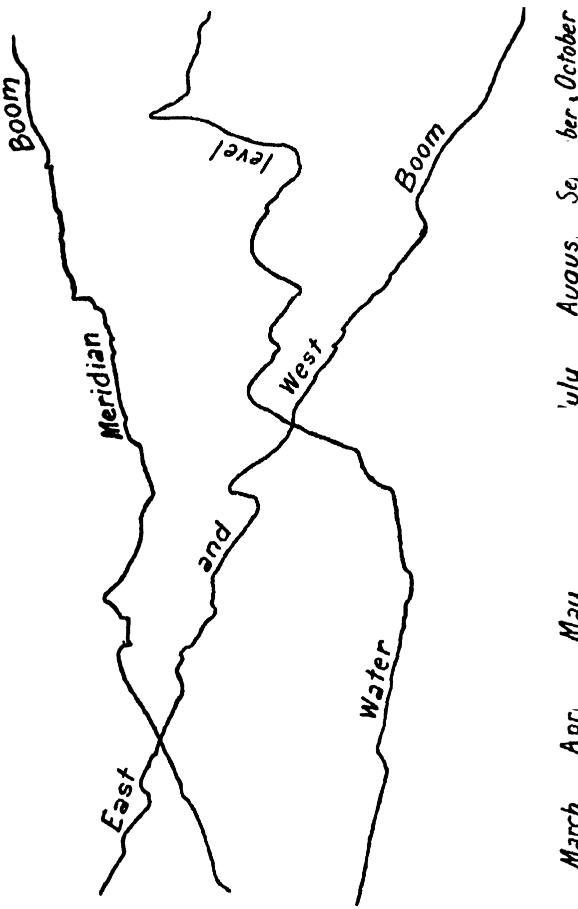



Figure 3.—Pendulum No. 3 (Potsdam Pendulum).

The deflections of the vertical registered by both booms are represented by changes in the ordinates of the curves. The curve for the meridian boom is drawn on a scale on which one centimetre corresponds to 1·74 seconds of arc.

While the curve for the east and west boom has a scale of 1·26 seconds of arc to one centimetre. The amount of deflection prior to 24th February 1915 is not known. In the case of the meridian boom an increase in the ordinate represents a deflection of the boom to the west. In the case of the east and west boom an increase in the ordinate corresponds to a deflection of the boom towards the south.

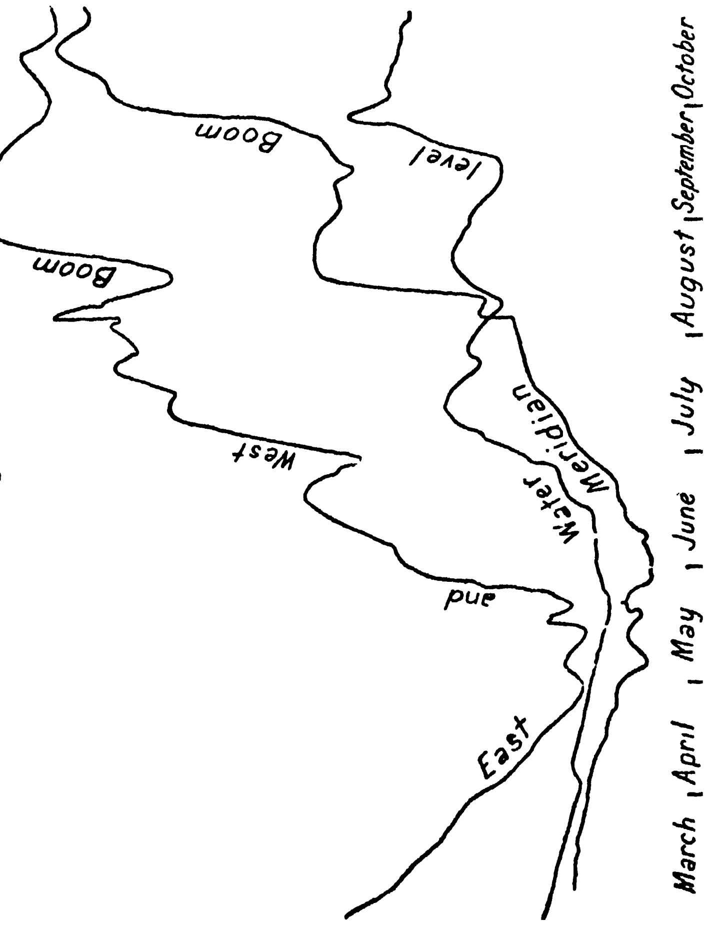
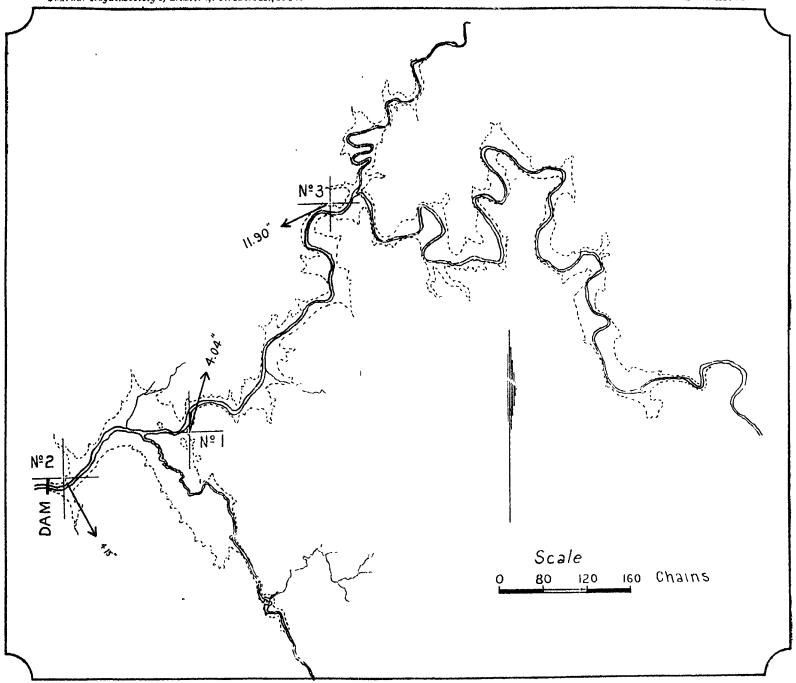



Fig. 3.

The curve of the water level is drawn to a scale on which one centimetre measures twenty feet of water. An increase in the ordinate corresponds to a rise of the water level. The actual water level at the 24th February, 1915, was twenty-two feet above the river bed at the site of this instrument. The abscissæ represent the times corresponding to the ordinates and are drawn to a scale of twenty days to one centimetre.

## Plate LXII.

This map indicates the position of the Murrumbidgee River and its tributaries within the area affected by the Burrinjuck Water Conservation Scheme. The positions of the river channels are marked in firm lines, and the area which will be submerged when the dam is full is represented by the dotted lines. The three pendulums (numbered 1, 2 and 3) are situated at the intersections of the three rectangular crosses marked on the map. The deflection of the vertical for each instrument for the period, 22nd February to 21st October, 1915, is stated in seconds of arc, and the direction of the deflection is shown by an arrow marked at each station.


N° 3
11.90"
4.04"
N° 1
N° 2
DAM
4.15"
Scale
0 80 120 160 Chains

[*From the Proceedings of the Linnean Society of New South Wales, 1912, Vol. xxxvii., Part 4, November 27th.*]

# NOTE ON THE RELATION OF THE DEVONIAN AND CARBONIFEROUS FORMATIONS WEST OF TAMWORTH, N.S.W.

BY L. A. COTTON, B.A., B.SC., ASSISTANT LECTURER AND DEMONSTRATOR IN GEOLOGY, UNIVERSITY OF SYDNEY, AND A. B. WALKOM, B.SC., LINNEAN MACLEAY FELLOW OF THE SOCIETY IN GEOLOGY.

(Two text-figures.)

The following notes are the result of observations made by us during a cycling trip from Tamworth to Mudgee, viâ Gunnedah and Coonabarabran, with the object of examining the strata.

The geology of the Tamworth-end of the section examined, has been discussed by Professor David and Mr. E. F. Pittman*, who have shown the characteristic rocks to be interstratified radiolarian cherts and tuffs, with occasional bands of limestone. They have also shown that, as a result of tectonic movements in the district, the strata have been folded into a sharp anticline between Moonbi and Tamworth, and they have indicated the position of a probable fault, with a throw of 9,000 feet to the east.†

Our section (Fig. 2) is a continuation of that given by Professor David and Mr. E. F. Pittman, and extends to a point three miles west of Gunnedah, the section being taken along the road. It is built up from dip and strike observations made, where possible, in the road-cuttings. These are represented on the map. Unfortunately, relatively few of these were obtainable, on account of the extensive development of recent deposits. These consist chiefly of surface-alluvials, and one large bed of river-gravels, at least 60 feet thick, containing pebbles about 3 or 4 inches in diameter, which extends four miles on either side of Somerton.

* "On the Palæozoic Radiolarian Rocks of New South Wales," Q.J.G.S., Vol. lv., 1899, pp.16-37.

† *Op. cit.*, Plate 3.

The section is not detailed on account of the difficulty of obtaining outcrops, and also the short time at our disposal. It is intended to illustrate, in a general way, the lithological character and structural features of the strata.

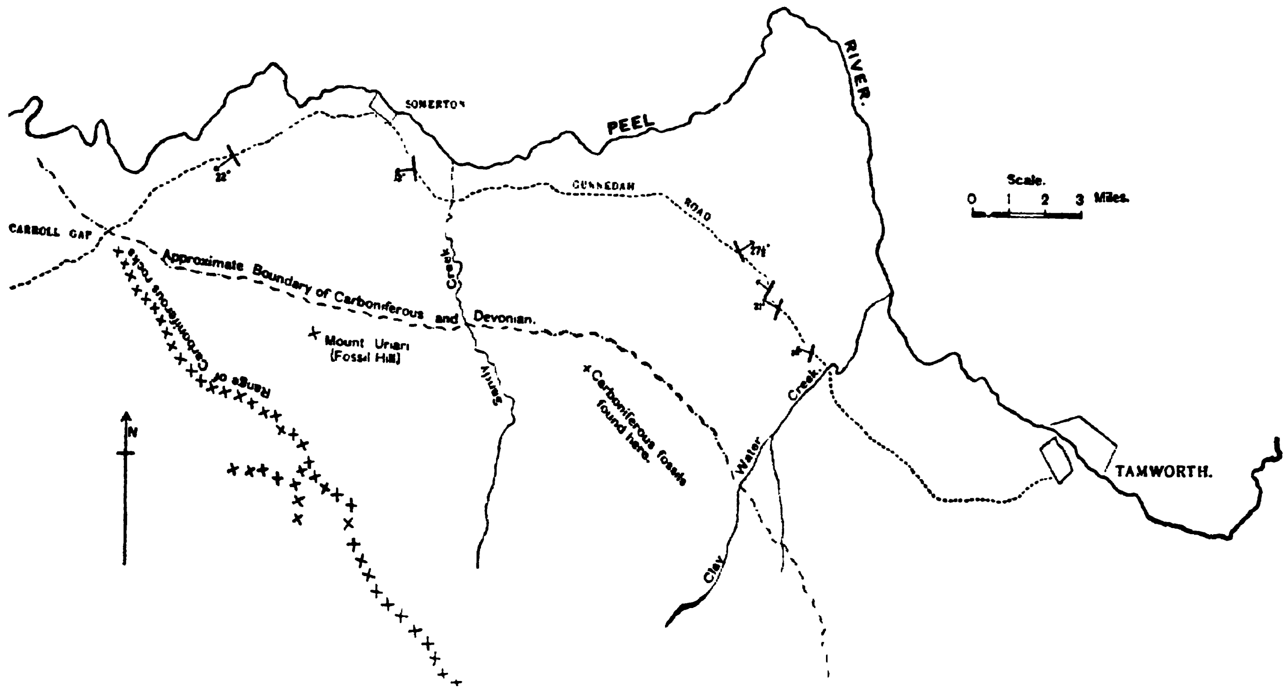
From Tamworth to within two miles of Carroll Gap (see Fig. 2), the rocks consist of interbedded tuffs and cherts, with one characteristic band of limestone. The tuffs and cherts exhibit considerable variation in their development. In some places, the tuffs appear massive, with very little chert, and in others (particularly the cutting near the 10-mile peg from Tamworth) there is very little associated tuff with the chert. Occasionally, tuffs and cherts are closely interstratified, as at a point about 8½ miles from Tamworth, where six bands of each were observed in a thickness of about 20 feet of strata. The bed of limestone referred to, is about 10 feet thick. It is a black, fine-grained rock, characterised by the presence of small, lath-shaped crystals about 4 mm. by 0·5 mm. Examination under the microscope and treatment with HCl show that they are composed of calcite, but their distribution suggests that they are replacements of some original structure. This was observed in three distinct places, viz., 5·2, 10·7, and 21·4 miles from Tamworth.

The plotting of the dips on the map showed that we were dealing with a series of anticlines and synclines, and the strikes indicated that these were tilted. From the information obtained, we calculated that the axis of tilt is about N.3° W., and the amount of the tilt from 6-7° towards the north. Reference to the section (Fig. 2) will show how these folds harmonise with the anticline east of Tamworth.

The presence of quartz-reefs in the roading cutting 10 miles from Tamworth, observed by Messrs. Harrison and Aurousseau, renders it not unlikely that the Moonbi granite-series underlies this portion of the section.

The most westerly observation of the dip of this series was at a point about two miles east of Carroll Gap. Between this point and Carroll Gap itself, outcrops are obscured by recent alluvial, and at the latter place, there is a bold outcrop of limestone dipping to the

Fig. 1.—Route-map, Tamworth to Carroll Gap.



east at about 80°, containing Carboniferous fossils as follows:—*Zaphrentis, Michelinia tenuisepta, Spirifera, Euomphalus,* and *Loxonema.*

This is followed, to the west, by a conformable series of tuffs and slates, the dip being in the same direction, and decreasing in amount as we go west.

There is a well-marked physiographic break at this point, probably due to differential erosion.

The sudden discontinuity in the dip and the general appearance of the country lead us to suggest a probable fault to the east of the limestone, letting down the Carboniferous area.

The lithological resemblance of the strata between Tamworth and Carroll Gap to, and the continuity of its folding with the Devonian series of Tamworth, as well as the marked discontinuity with known Carboniferous to the west, leave little doubt but that this series is of Devonian age.

The presence of Carboniferous fossils† at the localities marked on Fig. 1, suggests that the boundary is approximately as represented on that diagram.

The Carboniferous series may be intruded by the porphyrite indicated in the section.

From this point, an alluvial flat extends to a spot about two miles west of Gunnedah, being only interrupted by a ridge of aplitic granite three miles east of that town. At the western edge of this alluvial plain, there occurs a stratified rhyolitic tuff, probably of Carboniferous age, which is overlaid by Permo-Carboniferous Coal-Measures. Further to the west and south, these Coal Measures are capped by Triassic sandstones and claystones, as at Mullaley, where specimens of *Stenopteris* were obtained from a well in the town itself.

† The following have been recorded from Mt. Uriari by Mr. W. S. Dun:—*Zaphrentis, Productus semireticulatus, P. longispinus, P.* cf. *Murchisoni, P. undatus, Orthis resupinata, O. australis, Spirifer striata, S. pinguis, Dielasma sacculum, Entolium aviculatum, Aviculopecten* sp., *Euomphalus pentangulatus, Dentalium, Orthoceras* sp. ind.

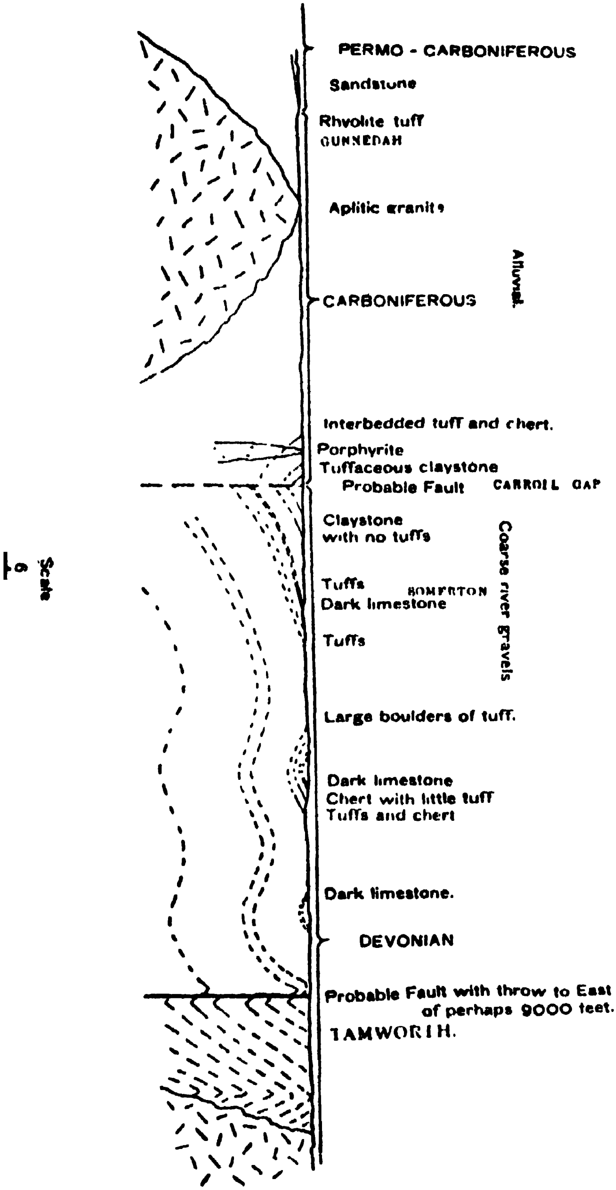



Fig. 2.—Section, from Tamworth to near Carroll Gap.

Mr. R. H. Cambage has recently found Carboniferous rocks, consisting of andesite and also cherty shales with *Rhacopteris*, just to the north-west of Currabubula. These shales strike in a north-westerly direction, and dip fairly steeply to the south-west. This point is about 25 miles S.S.E. from Carroll Gap, where Carboniferous rocks occur on the road from Tamworth to Gunnedah. This discovery shows that the whole length of the Peel Range, from Carroll Gap to Currabubula, is probably composed of Carboniferous rocks.

*Reprinted from Report of the Australasian Association for the Advancement of Science. Melbourne Meeting,* 1913. *Vol. XIV.*

# PRESIDENTIAL ADDRESS

TO

# AUSTRALASIAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

BY

Professor T. W. EDGEWORTH DAVID, C.M.G., B.A., F.R.S., F.G.S., Hon. D.Sc. Oxon.

In the first place, let me bid you, who are here gathered together to honour the principles for which our Association stands, and to share in its work, a very hearty welcome to this noble hall, a building sacred to the memory, not only of its beneficent founder, but also to that of those many who have made the pursuit of knowledge for its own sake the watchword of their lives. Such men and women, whether students or teachers, whether high or low in the world's esteem, are surely those whom our association delights to honour; and we feel the inspiration of their worthy lives present with us here in this hall to-night.

Next let me thank you for the unprecedented honour you have done me in electing me a second time president of our Association. I am deeply touched by the trust you repose in me, more especially when I know what that trust implies, for it means, not only that I have the high honour of presiding over this distinguished gathering, but, further, that you hope, in electing me to this office, that I may have the unique responsibility of representing our Association on what we all hope will be an epoch-making occasion, the visit to the Commonwealth, in 1914, of that mother society, of which we aspire to be a not unworthy daughter, The British Association for the Advancement of Science. Such trust fills one with a feeling of one's own unworthiness, and a sense of many shortcomings, and only your kind and unanimous will that I should act has led me to accept office in the firm belief that I can count in every one of you a friend who will not fail in time of need, and

the needs are likely to be many. In this belief, gladly and gratefully, I have accepted. I am aware that a very high standard has been set me by my predecessor in this office, for no one could have served the interests of our Association more ably or strenuously or conscientiously than Professor Masson. It is my pious wish to follow in his footsteps.

Next on the occasion of this the fourteenth meeting of our Association, it would surely be meet that we send a grateful greeting to our founder, Professor Liversidge. Our latest accounts of him show that he is strong and well, and after so many years of strenuous teaching and organizing work is now walking the Elysian fields of research.

Next I would remind you that recently there has passed away from among us one who has done a unique work for Australian science, in the branch of Ethnology, F. J. Gillen. I feel I cannot do better than quote the following sympathetic obituary notice that has recently appeared about him in *Nature*, 12th August, 1912:—" In Australian papers which have just come to hand we regret to see the death of Mr. Francis James Gillen. Anthropology has thus lost a conscientious and devoted worker, whose world-wide reputation has been well earned in a fast-vanishing field of investigation, which, unfortunately, attracts far too few men of Mr. Gillen's type. It is now forty-five years since he entered the public service of South Australia, and his official work caused him to become virtually exiled to the heart of the Australian continent; but he devoted his spare time to the study of the aboriginal people among whom he lived, and it is no exaggeration to say that he acquired a much more intimate knowledge of the customs and beliefs of the most backward race of mankind now in existence than all other investigators had been able to collect; and this wealth of accurate information was put to the best use when Mr. Gillen collaborated with Professor Baldwin Spencer, F.R.S., of Melbourne, and produced a series of the most discussed volumes that have ever been contributed to enthnological literature. The opportunities for such investigations as Mr. Gillen carried on are abundant, but with the rapid intrusion of European customs into every corner of the world, they will soon be gone for ever. It is thus with especial gratitude that all students of mankind will always regard the labours of such men as the late Mr. Gillen, who have seized the opportunities presented by their daily occupations, and rescued for posterity an accurate knowledge of the fast-vanishing customs and beliefs of primitive people." I might add that he was formerly president of the ethnological section of this Association. The sympathy of all of us will I know be extended to those who were near and dear to him, as well as to his close friend and fellow-worker, Professor Baldwin Spencer. The co-operation

of these comrades has brought home to us the lives and thoughts of our aborigines just in time to save them from oblivion. They have, indeed, protected the aborigines from the wicked practices of so-called civilized man, and set this ancient and honorable people in their right place. Science and humanity owes them both a deep debt of gratitude. Long may his comrade be spared to carry on the noble work to which he has devoted himself with such signal success and singleness of purpose never more in evidence than in his recent protectorate of the aborigines in Northern Territory.

We welcome him warmly to-night, returned after so much hardship and moving accidents by flood and field, and congratulate him on the recent publication of yet another charming book on Central Australia and its inhabitants.

The action of the Federal Government in organizing the recent scientific expedition to Northern Territory, in which Professors Gilruth and Spencer, Professor Woolnough, and Dr. Breinl, took part, will doubtless highly commend itself to the general public, no less than to workers in science. The reports already furnished all show that Northern Territory has far greater possibilities than, probably, most of us ever imagined in regard to both its pastoral and mining future. There can be no question that a thorough and systematic botanical survey should be undertaken before the native Flora becomes intermixed with alien plants. Many botanists might co-operate in this work. I would suggest at once the name of one who is acknowledged as a world-wide authority on the taxonomy of our eucalypts, and on the acacias, Mr. J. H. Maiden, and that of that eminent plant physiologist, Professor Ewart. It may also be suggested that the scientific reports on Northern Territory would be more complete if a meteorological report on it were obtained by some competent officer from the Federal Meteorological Bureau.

Those who have the privilege of knowing Professor Gilruth intimately will have every confidence that he will prove himself—indeed, he has already proved himself—an able and successful administrator, and this Association is surely grateful to the Federal Government for having placed our colleague in so high and responsible a position.

May we not express a hope that the Federal Government will shortly see its way to pursue the same enlightened policy it has adopted for the scientific exploration of Northern Territory, also to British Papua. Mr. J. E. Carne, F.G.S., Assistant Government Geologist of New South Wales, has, after a very arduous and most successful mission to Papua under the Federal Government, located there an extensive belt of oil-bearing sandstones, without doubt a continuation of the Great Burmese oil belt, which runs through Sumatra, Borneo, and Java, to Timor, and thence

New Guinea. This oil belt is full of possibilities, and should the supplies of oil prove satisfactory will be a boon to the Australian Navy. It may be said without exaggeration that, at the present moment, there is no more fascinating field for exploration in the whole world, since the South Pole has become overcrowded, than New Guinea. It is to be hoped that the Commonwealth Government will see its way to have such an expedition organized at an early date, and that when the representatives of the British Association arrive here in 1914 there will be a rich harvest of results from Papuan exploration to lay before them.

*Polar Exploration.*—Reference to the overcrowding of the South Pole recalls the fact that at present there are no less than three important expeditions in Antarctica; the German expedition, under Lieutenant Filchner; the British expedition of 1910-13, under Captain Scott; and the Australasian expedition, under Dr. Douglas Mawson.

Of the recent Antarctic expeditions, one might first touch on that of Amundsen, with special reference to his scientific results. Much has been said and written about his want of candour in neglecting to inform the scientific world, and particularly the leader of the British Antarctic Expedition, Captain R. F. Scott, much earlier than he did of his intention to compete in the race for the South Pole.

It is certainly to be regretted that no information of his intention to deviate from the original purpose of his expedition was made before the *Fram* left Norway. At the same time the important fact must not be overlooked that when Amundsen reached Maderia in November, 1910, he sent a cable to Captain Scott, who was then at Lyttleton, in New Zealand:—

"Beg inform you am taking *Fram* south."

Now it has been publicly stated in Australia and elsewhere that Amundsen stole a march on Captain Scott, and anticipated him in point of time in arriving at winter quarters in the Antarctic. This charge is wholly unfounded. Captain Scott was well aware, as the sequel proved, that Amundsen intended to make a dash for the South Pole. Scott's subsequent action before he left New Zealand proves this. He was not aware what part of the Antarctic continent exactly Amundsen would use as his base.

As a matter of fact, Scott was able to arrive at his base at Cape Evans, near Mount Erebus, several weeks earlier than Amundsen arrived at the Bay of Whales, the point of the east side of the Great Barrier selected by him as his base.

In the absence of any accepted code on the ethics of Pole jumping, it may fairly be stated that after Amundsen's cablegram to

Captain Scott, the South Pole might have been considered anybody's Pole; either the Norwegians, or the Japanese, or the Germans, or the British, for the expeditions representing all these peoples had by this time entered the field as competitors. As the result of his own consummate skill, forethought, capacity as a leader, and that genius which lies in the capacity for taking an infinity of pains, backed up by the record of a heroic past, and supported by a brave band of as equally heroic countrymen, Amundsen, as the world knows, secured the much coveted prize of the South Pole for the flag of Norway. Knowing full well, as we do, that Amundsen's dash for the South Pole was his last desperate throw to save his expedition, planned for the North Pole, from financial ruin, we can surely afford to make light of his slight departure from usual scientific etiquette, all the more because of the glorious record the British nation already holds in polar exploration, and can congratulate heartily and generously this hero of either Pole, and his brave companions, on the splendour of their achievement. Achieve the Pole they certainly did, as the most rigid scientific scrutiny of their numerous accurate observations proved that they must have passed within a few hundred metres of the Pole, and possibly have been even closer.[1]

It has been said that the scientific results of such a dash are meagre. Such a conclusion is disproved by the results, for although they do not bulk as large as those of Captain Scott's expedition, the geographical, meteorological, and oceano-graphical results are of extreme and unique interest.

In the first place, Amundsen's march to the Pole, and the explorations of his lieutenant, Prestud, in the direction of King Edward VII. land, showed that large masses of land, either immense islands, or low continents, with deep inlets, bound the Great Ice Barrier on the east, and southwards to the Antarctic Andes. It will be observed on the map exhibited that the Antarctic Andes make a great swerve from their south-easterly trend in the King Oscar Mountains, near where the Heiberg Glacier joins the Barrier; the trend southerly from this point being towards the S.S.E. This suggests a possibility of the Antarctic Andes after all, perhaps, extending into the eastern side of Weddell Sea, near Coat's Land, though this is by no means certain.

In these Andes, Amundsen discovered the highest mountain yet known in Antarctica, called by him Frithjof Nansen, 15,000 feet in height.[2]

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[1] Subsequent observations (with a theodolite) by the late Captain R. F. Scott and his heroic comrades prove that the spot where Amundsen planted the Norwegian flag was within half-a-mile of where they calculated the actual South Pole is situated.

[2] The late Captain R. F. Scott and Sir Ernest Shackleton discovered almost equally high mountains respectively in Mount Markham and Mount Kirkpatrick, the latter to the north-west of the Beardmore Glacier, the former about 80 miles further north.

Amundsen's meteorological results show that the barometric pressure at the Bay of Whales is lower in winter than in summer, a fact of great significance, confirming the previous observations of Scott, Shackleton, and the German Antarctic expedition under Drygalski. Fifty per cent. of the air currents at the Bay of Whales, sufficiently strong to be termed winds, came from the east. The lowness of the temperatures recorded at Framheim, in the Bay of Whales, at a latitude 78 deg. 38 min. south, longitude 163 deg. 37 min. west, was as remarkable as it was unexpected.

The winter there at Framheim was no less than 21.6 deg. F. colder than it usually is in McMurdo Sound, where the British Expedition wintered.

During August, 1911, the average temperature at Framheim of this, the coldest month, proved to be no less than —48.1 deg. F. The first abortive attempt made in September, 1911, to reach the South Pole proved to Amundsen that, at a distance of only about 25 miles south of the Bay of Whales, the temperature was about 17 deg. F. lower still. The latter point is in lat. 80 deg. south; possibly at 82 deg. or 83 deg. south, the temperature is cooler still. When one reflects that Hann and Meinardus have independently calculated the temperature at the South Pole, reduced to sea level in winter time, that is for the month of July, as only —28 deg. F., the great importance of Amundsen's discovery becomes apparent.

There is an immense pool of intensely cold air lying on the surface of the Great Barrier, remote from the stirring-up effects of high mountain ranges like the Antarctic Andes. Thus, we have the remarkable condition of this great lake of cold air, not only much colder than the temperature of the South Pole, reduced to sea level, but perhaps even colder than the South Pole itself, though the latter has an altitude of about 10,260 feet, whereas the surface of the Great Ice Barrier is not more than about 200 feet above the sea. An interesting analogous instance of a region of greater cold than the South Pole itself occurs in Northern Siberia. There at Verkhoyansk, the lowest temperature ever recorded at any part of the world has been met with, namely, —96 deg. F., that is 122 deg. F. of frost.

The geological specimens brought back by Amundsen, and examined in Christiana, reveal the fact that the rocks of the Betty Mountains to the south of the Ross Barrier (Great Ice Barrier) are formed of granite with veins of aplite. Similar rocks were obtained from Scott's Nunatak, in King Edward VII. Land, together with schist, gneiss, white granite, granodiorite, and diorite. No less interesting are the oceanographical results secured by the *Fram* on her long and patient surveys in the South Atlantic, as shown on the accompanying lantern slides. It was found that

whereas the isotherms at the surface of the ocean stretch in a general south-west to north-east direction across the South Atlantic, the warm water lying towards the north-west, at a depth of 400 metres, the isotherms are quite different from those on the surface.

The 400 metres isotherms show pools of relatively warm water underlying colder water, and bounded equatorwards by much colder water, the difference in temperature being no less than 27 deg. F.

Some analogous temperature distributions have already been proved between Iceland and Norway, where the relatively warm, but more saline, waters of the Gulf Stream dive underneath the colder, but fresher, waters coming from the Arctic Ocean.

Gravity and magnetic observations were also obtained by this expedition. There can be no doubt that the value of Captain Scott's scientific observations, especially the meteorological, will be greatly enhanced by the fact of simultaneous observations having been taken by Amundsen. In reference to the German expedition under Lieutenant Filchner, at present we know practically nothing, but can be quite confident that in the almost wholly unexplored region of the Weddell Sea Quadrant, he and his comrades will contribute to raise higher still the reputation of their nation, already second to none in the world, for accuracy and thoroughness in all kinds of scientific research. Next, in regard to Captain Scott's expedition. While there is much subject for congratulation, the fact cannot be concealed that the news which the *Terra Nova* will probably bring us late in March will be looked for with a keenness tinged by anxiety. There can, in my opinion, be scarcely a shadow of doubt that Captain Scott and his gallant band, after desperate struggles, testing the human system to its utmost limit of endurance, struggles and hardships from which Amundsen and his comrades, from their superior experience and knowledge, were exempt, have actually reached the South Pole and discovered the tent and flag, and other marks that were left by Amundsen. One cannot but sympathize with the poignancy of the disappointment of Scott and his party when they found, after all their heroic struggles, that they had been anticipated. But the story of their magnificent courage in the face of appalling difficulties, is one which will go down as inspiration to noble effort for all time.[1]

A useful summary of what promised to be the richest harvest of scientific research ever gathered in the Antarctic has already been given by Mr. J. H. Maiden, our general secretary, whom we all

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[1] This was, of course, written before the sad news of the Polar tragedy had reached Australia. The inspiration remains, but alas for the brave spirits that have passed!

rejoice to see restored to his normal robust health, in his presidential address to the Royal Society of New South Wales, delivered 1st May, 1912. Extremely important meteorological observations, especially with reference to the higher atmosphere and its temperature, pressure, and movements, have been obtained by Dr. Simpson, who, by means of unmanned balloons, has been able to study accurately the conditions in the higher atmosphere of the Antarctic up to heights of about 26,000 feet.

His method of recovering the tiny meteorograph apparatus no bigger than a watch when it fell sometimes at a distance of as much as 10 miles from where it was sent up, by means of a delicate silken thread paid out automatically as fast as the balloon rose, and set free by a timed attachment which dropped the self-recording meteorograph from the balloon, was as simple and effective as it was ingenious.

Important researches in physics are being carried on by Mr. S. Wright, who in the absence of Dr. Simpson and Mr. Griffith Taylor, is now in charge of both the meteorological and magnetic work formerly undertaken by Dr. Simpson. One of the most interesting results obtained by the biologist, Mr. Lillie, and Mr. Nelson, has been the securing of enormous quantities of that remarkable vertebrate *Cephalodiscus*. Some very interesting geological surveys and glacial explorations were conducted by Mr. Griffith Taylor and Mr. Frank Debenham.

One may rely on a young scientist of Mr. Taylor's genius to make important original contributions to our knowledge of these branches of knowledge, and, to judge from the accounts from head-quarters of the work of Mr. Frank Debenham, it is clear that it too will form a valuable addition to our knowledge of the petrology and physiography of the Ross Quadrant. Mr. R. E. Priestley, my geological colleague in the Shackleton Antarctic Expedition, though cramped, geologically, at Cape Adare on account of the surrounding inaccessible mountains, has accomplished most useful meteorological work, and no doubt has obtained valuable geological information, when, as a member of Lieut. Campbell's party, he explored the region around the base of Mt. Nansen.

Although there is every reason to hope that Lieut. Campbell's party have long ere this returned in safety to head-quarters, there is still some little room for anxiety. Last February, the *Terra Nova* attempted on several occasions to take up this party, but were prevented by dense belts of pack ice, which prevented the ship getting within less than about 10 miles of the shore. Probably they would either winter near Evans' Cove, opposite Mt. Nansen, or would retreat by the very difficult and dangerous route along the coastal plain, intersected at intervals by more

or less heavily crevassed glaciers. Messrs. Taylor and Debenham earlier in the year found themselves left in a somewhat similar plight, but at a nearer distance to their base. By making back inland a few miles up the slope of the Piedmont ice they were enabled eventually to travel by a fairly practicable route back to winter quarters. It is devoutly to be hoped that Lieut. Campbell's party have been equally successful.

Some little anxiety also exists in regard to Captain Scott's party. When Lieut. Evans and his two colleagues were despatched back to head-quarters by Captain Scott, when the latter remained with his party within 127 miles of the South Pole, there was not the slightest suspicion of any member of either party being in any but the most robust state of health. Unfortunately, about a fortnight after parting from Captain Scott, when traversing the Great Ross Barrier, Lieut. E. R. G. R. Evans, R.N., was attacked by scurvy, and, but for the extreme heroism of his two comrades, one of whom became later also affected by scurvy, though slightly, there is no doubt that he would have forfeited his life in the cause of geographical exploration.

There is one consoling reflection to which Lieut. Evans attaches great weight, when one considers the probability of any of Scott's party, subsequent to their reaching the Pole, and on the return journey, having been afflicted with scurvy, and that is that Lieut. Evans, on account of six weeks of strenuous work on the Ice Barrier laying depôts, had to exist all this time with his party on tinned provisions only, whereas the remainder of Scott's party were at the time supplied regularly with fresh meat at winter quarters.

Lieut. Evans considers his attack of scurvy was probably due to pemmican—a meat and beef-fat paste—which had become unfit for food, and induced scurvy, which is perhaps a species of blood poison. In spite of this small room for anxiety, there is every reason to hope that Scott and all his party, after accomplishing more scientific work, such as the rounding of the boundaries of the Great Ice Barrier, &c., and completing other research work in a manner never surpassed or equalled by any previous antarctic expedition, will all return, like Shackleton's expedition, without the loss of one single life.

Next in reference to the Japanese expedition under Lieut. Shiraze. They have appeared to have accomplished little beyond landing on the Great Ice Barrier at the Bay of Whales, where they met Amundsen, and studying the structure and crystallinity of the ice of the Barrier, and sending inland a sledge party, under

Takeda, for a distance of about 150 miles to the south-east of the Bay of Whales. They reached a latitude of 80° 5′ South. longitude 156° 27′ West. At their furthest point south-east there was no trace of any rock or earth visible, nothing but the whiteness of the ice surface, which descended by a gentle slope to the level of the Barrier. As the altitude at this extreme point was about 1,300 feet above the sea, there can be little doubt that land must underlie this area.

Lastly, we may glance at the important scientific expedition, the first of its kind despatched under the auspices of this Association, and under the leadership of Dr. Douglas Mawson, to that great unexplored region of the Antarctic which lies between the meridian of Tasmania and that of South Africa, and which, therefore, directly fronts our own southern coast.

My predecessor in this office stated in a vigorous and inspiriting address that it was "up to" us in Australia to do something on our own to explore this vast and, as yet, so little known continent which lies at our very door. It is now a matter of history that this Association responded nobly to their leader's call, and how, following that lead, generous individuals in the Old Country and patriotic citizens of this Commonwealth gave Mawson most effective support with their handsome donations, and we shall never forget the liberal and generous spirit in which the Commonwealth Government vied with the State Governments in supporting this first piece of new and arduous exploration ever undertaken by our country in the field of South Polar research

Three stations have been successfully established respectively at Macquarie Island, Adélie Land, and at the Great Termination Glacier, a little east of the old head-quarters of the German expedition near Gaussberg.

The landing by Captain J. K. Davis and Wild's parties at the summit of this great glacier cliff, over 100 feet above sea-level, was a feat of daring and decision which has certainly never been surpassed in the history of the exploration of either Pole.

The meteorological and glacial observations at Termination Glacier are likely to prove of great interest. Captain Davis made a very interesting discovery on the voyage eastwards towards Adélie Land; he found that a huge ice barrier prevented his sailing his ship within 80 to 100 miles of the track formerly followed at this distance further to the south by Commander Wilkes in 1839. In matters of longitude, it is of course easy even for expert navigators to err, but it is surely less likely for so experienced a navigator as Wilkes to have been at all seriously out in his latitudes, certainly not to the extent of 80 to 100 miles.

The provisional conclusion may be drawn that, since the time of Wilkes' voyage, there has been a solid advance northerly of the front of the Great Ice Barrier in this locality to the extent of about at least 80 miles.[1] It is the more remarkable, in view of the fact that, in the Ross Sea region as well as in the Graham Land region of the Antarctic, there is every evidence of an extensive recent retreat of the glaciers and ice-fields in general.

At Adélie Land, Mawson has established his head-quarters at a bay called by him Commonwealth Bay. He has with him an expert magnetic observer in Mr. E. N. Webb, of New Zealand, trained under Mr. E. Kidson of the Carnegie Institute; and in the matter of magnetic instruments, is probably better equipped than any preceding Antarctic expedition.

The proximity of the base of the South Magnetic Pole renders continuous observations here of extreme scientific interest. It was Dr. Mawson's great ambition to make good the work already begun on the South Magnetic Pole by the Shackleton Expedition, and to connect the name of Australia indissolubly and honorably for all time with the work of exploring this wonderful focus of the magnetic force in the Southern Hemisphere. When it is considered that the magnetic lines of force in the Southern Hemisphere are chiefly controlled by this Pole, and that the Pole has undoubtedly been in movement since its position was theoretically calculated by Sir James C. Ross in 1840, and that upon the trend of these lines depends the various directions in which ships' compasses point on the Southern seas, it will be seen that any advancement of our knowledge of these magnetic conditions will not only be of great scientific use and necessity, but will also make for greater accuracy and security in the navigation of the many thousands of ships which yearly furrow our southern seas.

If the work in this department of magnetism alone be fully and successfully accomplished, as there is every reason to believe it will have been, the expedition will have fully justified its existence in the eyes of the world, as well as in those of this society, which originated it; and the patriotic individual donors, and the Federal and State Governments of the Commonwealth, as well as the British Government, will feel convinced that the money they have so liberally contributed has been spent on a most worthy object. But there are many other branches of science which we hope will benefit materially from the Australasian Antarctic Expedition.

[1] On the other hand it is possible that this barrier may be formed of vast fleets of bergs cemented together by sea ice, and with the original spaces between them filled in with drift snow. Such a mass of ice would be analogous to the "Schollen" ice, described by Drygalski, to the west of the wintering station of the Gauss, near Gaussberg.

Reference has already been made to meteorology. Our Federal Meteorologist, Mr. H. A. Hunt, informs me that the weather data, which are sent him by wireless from Macquarie Island, prove the closest connexion between our Commonwealth weather conditions and those of the Sub-Antarctic. The Rev. D. C. Bates, the Meteorologist to the Dominion of New Zealand, confirms this relation between the weather conditions of Macquarie and those of New Zealand. It is true that Macquarie Island, being west of Sydney, supplies data of more value for forecasting in New Zealand than in Australia; but these data are absolutely essential for a full understanding of Australian weather conditions, and it is to be hoped that, in the near future, arrangements may be made for the continuous upkeep of this station. The cost is estimated at only about £800 to £1000 a year. For the benefit of commerce and science, it is greatly to be hoped that this suggestion will be strongly supported. The fact that the Australasian Wireless Company, with a comparatively small 1½-kilowatt dynamo, have been able to transmit messages which have easily been received in Sydney, and at times even in Suva and Perth, speaks volumes for the perfection of their system and the skill of their operator.

Members of the Association will, I trust, be pleased to hear that a complete wireless receiving outfit has recently been dispatched in charge of Captain Davis to Adélie Land. This should be capable of receiving messages transmitted from a distance of fully 2,000 miles. Up to the present, Mawson's wireless messages, with wearisome reiterations, affirm the fact that they have been unable so far to receive a single message from anywhere.

It is now hoped that, as soon as the *Aurora* reaches Mawson's base, messages may at once be freely exchanged between Australia and Adélie Land, either *viâ* Macquarie Island or direct, and what is most important, time signals may be interchanged between the Melbourne Observatory and Adélie Land; and so, with the help of Mr. P. Baracchi, for the first time in the history of the Antarctic exploration, a fundamental meridian of longitude may be accurately established for Antarctica.[1]

The transmission of accurate time signals will also much enhance the value of the magnetic and other observations.

In the charting of a new coast, much valuable help is likely to be rendered by an able and enthusiastic young Dutch geologist, J. Van Waterschoot Van der Gracht, who is a brother of the Government Geologist of the Netherlands, and has also distinguished himself in West Antarctica in making accurate and most artistic cartographic drawings of the Antarctic coast and that of Terra del Fuego.

[1] A short time after this was written, almost daily communication has been established by wireless between Dr. Mawson's base at Adélie and Australasia.

This enterprising and magnanimous young explorer has placed his services gratuitously and unreservedly at Dr. Mawson's disposal, a bright example of the true scientific spirit. It is thought that a particlularly rich biological collection will be gathered together by Mr. J. Hunter and his assistants which will supplement the collection already made by Mr. Hamilton at Macquarie Island, and by Mr. E. R. Waite and Professor Flynn on the recent cruise of the *Aurora* in Sub-Antarctic waters.

The first Oceanographic cruise of the *Aurora* did not prove very fruitful in result, chiefly on account of the extremely stormy weather encountered throughout. A second cruise was more successful, and resulted in a discovery of importance, that of an extensive submarine ridge about 200 miles to the south of the southern end of Tasmania.

This ridge rises from depths of about 2,200 fathoms to 600 fathoms of the surface, and is therefore 9,600 feet in height. It is a monument most suggestive of that former union of Tasmania and Antarctica which the past and present flora of Tasmania, South America, Antarctica, and New Zealand, seem to postulate, and which has been so ably argued by Mr. C. Hedley recently in his paper to the Linnean Society of London.[1]

It is not generally realized that, in going to the coast of the Antarctic, so close to the Antarctic circle itself, Dr. Mawson and Captain Davis took a tremendous risk. It is well known that near the latitudes of 60 degrees and 65 degrees is what the German meteorologists call the "gutter" (die Rinne) of the atmosphere, that is a great world furrow of extremely low pressure running E. and W. into which blow, with a persistence and fury elsewhere unparalleled, the blizzards of the south and the "Roaring Forties" of the north.

Navigation in those seas is fraught with many great dangers; but, nevertheless, we hope to see every member of the Expedition return safe and sound to us in March or April of this year, when we shall all join in giving them a very warm welcome, and all honour for the endurance and courage with which they have faced such great privations and perils in the cause of science.

*Visit of the British Association for the Advancement of Science to Australasia in July, August, September*, 1914.—An important feature, and in some respects a serious drawback in the location of Australasia on the face of the globe, is its extreme isolation from the great centres of thought in other

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[1] Proc. Linn. Soc. London 1911-12, pp. 80-90, "The Palæogeographical Relations of Antarctica."

parts of the world. Thus for most of us interchange of ideas with the scientific world at large is effected chiefly through the means of scientific journals and magazines and reports of scientific societies, as well as, but to a much more limited extent, by personal correspondence. One lacks here, for the most part, except on occasions like the present, the opportunity for personal contact even with one's fellow workers in science in Australasia; and undoubtedly the most precious product from gatherings such as these is the charm and inspiration which comes from personal contact with one's fellow workers. Those of us who are privileged, on rare occasions, to visit the centres of thought in the Old World fully realize how personal contact with master minds in the Old World brings us in a few hours nearer to the truth than we could have come as the result of reading of magazines for many months. The value of such meetings in this respect is, therefore, inestimable.

Australasia has experienced the good that has resulted from personal visits of Australian Prime Ministers and Premiers to the Old World, of the visit to our shores of the Empire Chamber of Commerce, the Scottish Agricultural Commissioners, &c. No less good is likely to flow to the Australasian world of science from the approaching visit of the British Association, and already we feel under a deep debt of gratitude to all those who have initiated this great movement.

Over ten years ago the idea of inviting the British Association to visit Australasia presented itself to the founder of this Association, Professor Liversidge. At that time we were much smaller and less wealthy communities than we are at present, and, not being federated, could not speak with one voice, nor draw on a common fund. Hence the project had to be postponed. It has been reserved for a distinguished member of the Council of the University of Melbourne, Dr. J. W. Barrett, who is no "little Australian," to bring the matter prominently before the notice of the authorities of this University. The co-operation of other Universities was as heartily given as it was sincerely sought. The scientific societies followed the lead of the Universities *con amore*, this Association taking the lead, and willingly lending its organization for purposes of forwarding the movement. My predecessor in this office, when visiting England in 1910, and attending there the meeting of the British Association at Sheffield, strenuously and successfully pressed the invitation on behalf of Australian science, an invitation which was officially conveyed by Sir George Reid. The State Governments of the Commonwealth, through Sir George, promised liberal railway concessions to the visiting members. It will be fresh within the recollection of all that a great wave of

joy went over the whole of our scientific community when we heard that our invitation had been accepted by the British Association; and that joy was all the greater when we learned later that the visitors from the British Association would comprise leaders in every branch of science throughout the United Kingdom, and that among them would be included Sir Charles Lucas. The Universities and science societies having thus moved the Government, Federal and State, to join in issuing the invitation, next approached the Federal Government with a view to their voting the necessary funds to defray the cost of the transit overseas of so large a number of scientific visitors. With splendid foresight and liberality the Federal Government voted the handsome sum of £15,000 for these expenses; and it is a particularly pleasing feature in this connexion that the question was treated as a purely non-party one, Mr. Fisher and Mr. Deakin assisting each other in every way possible to bring about this happy consummation. The Federal Government being the hosts of the visiting Association, have recently asked for the co-operation of the scientific workers in the various States, in order to make all the necessary preliminary arrangements. Each State is sending representatives to the Federal Council in Melbourne, which comprises political as well as scientific representatives from every State of the Commonwealth, the Prime Minister acting as chairman. The State Governments and municipalities have unanimously promised every support. So far the whole organization is working very smoothly. So much of its future successful working depended upon the selection of the right man to act as general secretary for the British Association, for organising their visit in Australia, that extreme care had to be exercised in his selection. All, I feel sure, will agree that the choice could not have fallen on a man who is more suitable in every way than our newly-appointed general secretary, Mr. A. C. D. Rivett. All that now remains is for each of us to work together with a will, in order to make this approaching visit of the British Association a real epoch-making event, not only in the history of Australian science, but in that of Australasia.

*Universities.*—University education is making rapid progress in Australia. Apart from the continued expansion of the older Australian Universities, one of which (Sydney) is now commencing to work under a new University Bill, which practically makes education free in all schools of the University for deserving students, there is the growth of the new University of Queensland, and the establishment of the University of Western Australia to be considered.

The University of Queensland, which at present has four professors and seventeen lecturers and demonstrators, will probably commence the academic year with no less than 200 students. At the University of Western Australia it is very gratifying to note that out of the eight chairs advertised, for which there was an aggregate of 230 applicants, no less than four have been given to alumni of Australian Universities, viz., the Chair of English to Walter Murdoch; that of Chemistry to N. T. M. Williams, D.Sc., both of Melbourne University; the Chair of Engineering to Hubert E. Whitfeld, B.A., B.E.; and that of Geology to W. G. Woolnough, D.Sc., both of Sydney University.[1] This fact speaks for itself as to the standard of Australian University teaching. Our hearty good wishes go with all these new professors no less than with their colleagues newly appointed from the Old World, and may we not wish this, the youngest of the Australian States, every success in its splendid academic enterprise!

*Australian Climate, Past and Present, with special reference to its control by Antarctica.*—Although no meteorologist, I have necessarily had, in the course of my geological work, to devote some little time to the study of that subject, and when in Antarctica, in 1909-10, during the long winter months when geological studies were all but impossible, concentrated my attention as much as possible upon the local weather conditions, and especially upon the problems of circulation of the upper atmosphere in that region.

It is proposed now to discuss the nature and circulation of the atmosphere in general briefly, and then to pass on to consider the circulation in the Antarctic and its influence on Australian climate, past and present in particular, with some notes in conclusion as to what appeared to be special needs, at present and in the near future, of Australasian meteorology.

First, this sketch may begin with a summary of what are probably the chief causes of the circulation of the atmosphere. Firstly, the circulation results from the spherical shape of the earth, which causes in turn the differential heating of the earth's surface by the sun, for an important fact must be emphasized,

[1] Since this was written, the Chair of History at Western Australia has been awarded to E. O. G. Shann, B.A. of the University of Melbourne.

that fully 99 per cent. of the earth's surface temperature is due to heat received by it from the sun, so that heat received from other sources, as from the internal heat of the earth, from radiative emanations, from planets or stars, may all be considered as practically negligible.

Next there is the factor of the different presentment of different parts of the earth to the sun's rays at different seasons of the year, due to the obliquity of the axis of rotation of the earth to the path in which the earth revolves around the sun. Next there is the factor of the rotation of the earth from west to east. This factor, as Ferrel has shown, leads to the tendency for any body in the northern hemisphere, whether moving in a north-south direction or in an east-west direction, or in any intermediate direction to be deflected towards the right. In the southern hemisphere the deflection is, *ceteris paribus*, towards the left.

Next there is the factor that the earth's surface is partl formed of land and partly of water, and next that the specific heat of water is about four times that of average land. In other words, land warms up, or parts with its heat four times as quickly as water does.

Next there is the factor that water, when vaporized, is lighter than air, and thus when present in appreciable quantities in air tends to float the air masses upwards, the molecules of water vapour acting like microscopic balloons, and so when conditions are humid, all other things being equal, atmospheric pressure is less than when the air is dry.

Next there is the factor that pure normal dry air is practically diathermanous, that is, it allows the sun's heat rays to be transmitted through it to the earth without itself undergoing any appreciable rise of temperature.

Next is the factor that the presence of any of the following substances in the atmosphere lessens its diathermanous properties, viz., water vapour, carbon dioxide, ozone, dust motes. Dust motes may come from ordinary surface terrestrial dust, lava dust from volcanic eruptions, or cosmic dust derived from the volatilization and subsequent condensation of meteors and meteorites.

Next is the factor that if air expands as it rises its heat becomes distributed over an increasingly larger volume. This so-called adiabatic expansion of air is followed by a fall of temperature at the rate of 1.6 degrees F. for every 300 feet of ascent.

Next is the factor that in places where the weather is calm, so that no convection currents of air are rising, bringing about this adiabatic fall of temperature, the fall of temperature of the atmosphere is at the rate of about 1 degree F. for ascent of 300 feet.

Next is the factor that outside the ordinary gases, such as oxygen, hydrogen, and carbon dioxide, which enter into the composition of the earth's lower atmosphere, is the vast vault of the higher atmosphere composed chiefly of hydrogen and helium, with small quantities or argon, neon, and xenon. These extremely light gases, as far as we are at present aware, play no very important part in our atmospheric circulation.

Next is the great factor, the importance of which has been realized only of late years, that at a height which varies chiefly with altitude, partly with surface atmospheric conditions, of from 27,000 feet near the North Pole[1] to over 50,000 feet at the equator and tropics, the temperature of the earth's atmosphere suddenly ceases to fall, and usually commences to rise again, after which, at a much higher altitude still,[2] it may fall again, but at an extremely slow rate. The bottom of this layer, the inversion layer, is now known as the isothermal line, and one of the greatest aims of modern meteorology, when dealing with the higher atmosphere is to determine the height temperature and movement of this isothermal line or surface. Practically it forms a ceiling over the top of the circulating portion of the earth's atmosphere against which all appreciable upward or downward or horizontal moving convection currents practically stop. The great discovery of the existence of the isothermal layer was made by the distinguished French meteorologist, Teisserenc de Bort, at the world-famous observatory at Trappes, near Paris, and almost simultaneously by Professor Assman, in Germany. It is beyond the scope of this address to discuss all the probable reasons for the existence of the isothermal layer. Two only may be given. Obviously the cessation upwards of convection currents from the lower atmosphere, when the isothermal layer is reached, is due to the fact that air which is getting colder by adiabatic expansion cannot force its way above air which is warmer than itself, and at the same time under less pressure than itself, as is the air at the base of the isothermal layer. The fact which most needs explanation is why, after a steady fall in temperature with

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[1] During the summer of 1906 Professor Hergesell concluded that over the Arctic Ocean near lat. 75° N., the isothermal layer there sunk as low as 23,000 feet.

[2] Professor Milham found recently that on 8th October, at St. Louis, Mo., U.S.A., lat. 38° N., the minimum temperature recorded occurred at 47,600 feet, while the same day at the maximum altitude attained, 54,100 feet, the temperature rose to −72° F., a rise of 18° F. (10° C.).

ascent, does such an inversion layer of warm air suddenly manifest itself? Two possible causes, which I would briefly mention, are the following:—

First, it is well known that the ultra violet rays of sunlight are largely absorbed in the higher atmosphere. In this process of absorption they appear to accomplish two kinds of work—the first, the conversion of some of the high-level oxygen into ozone; and as ozone is able to absorb heat even when dry, whereas oxygen does not, in the second place they warm the ozone.

Next it is pointed out that with one exception all the substances and conditions which lead to the lower atmosphere being alternately warmed or chilled disappear at a height of from 5 to 6 or 7 miles above the earth's surface. These substances, as already mentioned, are aqueous vapour, carbon dioxide, and dust, and the condition which obtains at the earth's surface, but not at the isothermal layer, is the conduction of some solar heat by contact with the land or water to those substances, and the consequent warming of the layer of the atmosphere next to the earth by the long waves of radiant energy, which are practically transformed waves from sunlight.[1] Of the three substances which go to bring about changes of temperature in the lower atmosphere, and so produce convection currents, only dust is met with above the base of the isothermal layer. This dust is excessively tenuous and minute. It is not of ordinary terrestrial nor of volcanic origin, but at this high level is probably wholly derived from the small amount of material resulting from the condensation of incandescent gases given off during the combustion of meteors and meteorites. Such dust would settle at an extremely slow rate through the atmosphere commencing at the point known as the radiant point of meteors, usually about 50 miles above the earth's surface. In this slow process of settling down, the dust becomes denser as the density of the atmosphere increases, and thus contact with this dust tends to slightly warm the higher atmosphere in the isothermal layer, the warming effect increasing downwards, but it is so slight that it is insufficient to produce effective convection. It is indeed the same process which results from warming of dust in the lower atmosphere, but in the latter case the dust is present in such appreciable quantity that its heating effect on the atmosphere is sufficient to bring about definite convection currents.

[1] For further information on the cause of the isothermal layer or upper inversion, see *Mount Weather Bulletin*. vol. ii, Papers by Humphreys, and Proc. Roy. Soc. Series A, vol. lxxxii, p. 43, Gold, also *Nature*, 1908–1909.

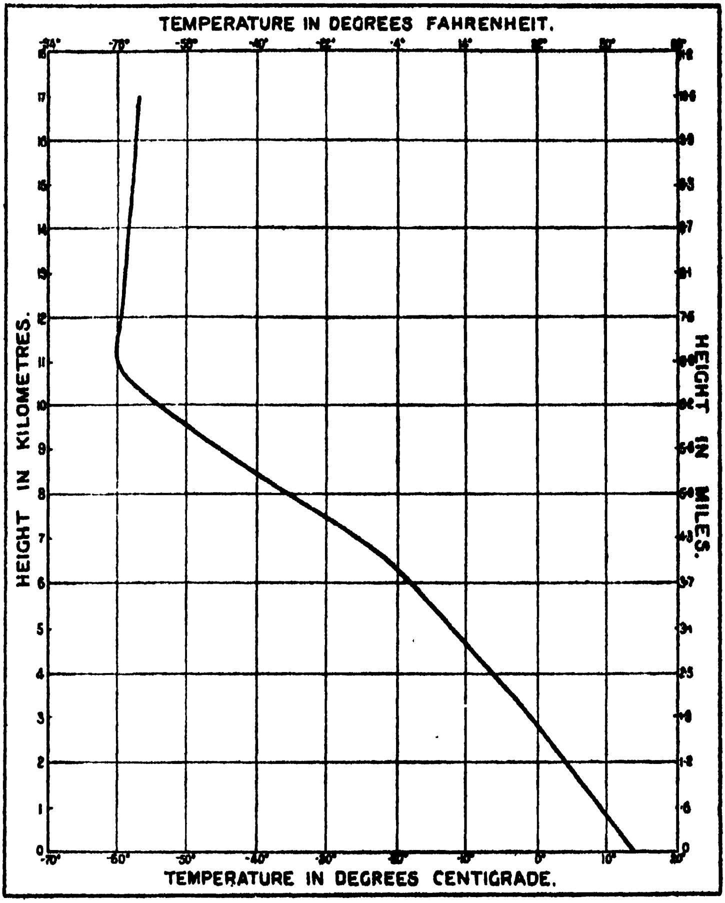


FIG. 1.

Curve showing temperature of atmosphere near Melbourne, up to height of 17 kilometres, from meteorograph record obtained by Mr. H. A. Hunt, Federal Meteorologist. The balloon carrying the meteorograph was released at the Central Weather Bureau, Melbourne, on 23rd May, 1913, and fell at 82 miles to E. 23 deg. S., at Yinnar, Victoria. The wind at Melbourne at the time the balloon was started was blowing from the south.[1]

[1] Through the kindness of Mr. W. A. Hunt I have been permitted, while this address was going through the press, to substitute this Australian record of the temperature up to and above the isothermal layer for the conventional curve which I exhibited at the meeting, the latter curve having been generalized from a number of observations in the Northern Hemisphere.

We are now in the position to consider the theories of atmospheric circulation. The starting point is naturally the differential heating of the equator as compared with the poles. In Fig. 2, the effect of this heating is illustrated in the case of the

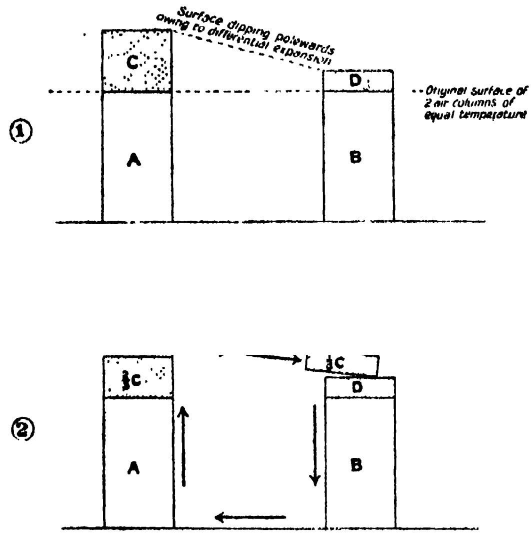


FIG. 2.

two masses of air, the one at the equator, the other on the poleward side of it. Both of them, it may be assumed, in the first instance, exert precisely similar pressure on the earth's surface, and have similar height, but as the result subsequently of the differential heating effect of the sun, the equatorial mass expands to a greater extent than the mass on the poleward side of it. So far, however, there is no apparent reason why there should be any circulation from the base of one column of air to the base of the other. The greater elongation of the equatorial column has no more increased its weight than the weight of a telescope is increased by being pulled out to its full length after it has been shut up. But now the factor of gravity comes into play. Gravity tends to pull mobile substances towards the centre of gravity in such a way that surfaces of those substances become tangential to the direction of pull. It will be seen that in the two columns of air *a* and *b* of Fig. 2, the plane touching their surfaces is no longer a tangent to either of the columns. The equatorial column is practically top heavy, and under the influence of gravity it sways over, and flows on either side of the equator in a poleward direction. As soon as the flow sets in from the top of the higher

column towards the lower column, and material is thereby removed from the former, weight is taken off the base of this column, and is added to the base of the poleward column, and thus equilibrium is disturbed through the lessening of pressure at the equator, and the increase of the pressure on the poleward side. There would then already be a tendency for the air at the base of the poleward column to flow in towards the equator, in order to equalize the pressure. Thus a steady transfer of air sets in from the summit of the great protuberant air belt, "Der Wulst," at the equator to the sub-tropical belts on either side of it. This is the great first principle of atmospheric circulation. We at once see the reason for the existence of a constant belt of low pressure at the equator, and two constant belts of high pressure in sub-tropical latitudes. These latitudes are respectively 37 deg. north in the Northern Hemisphere, and about 35 deg. south in the Southern Hemisphere. Their establishment at these particular latitudes is probably in part connected with the fact that on the surface of the sphere the areas between the equator and the poles balance themselves at 30 deg. north or south of that equator. If the air masses on the equator side of 30 deg., and that on its poleward side possessed exactly the same density, they would balance each other exactly at 30 deg. north or south of the equator. But on account of the greater cold and consequent greater density of the poleward lying air, as compared with the equatorial air, it would probably be necessary to take in more territory than is represented by the strip extending from 0 deg. to 30 deg., in order to secure a mass of air which would approximately equipoise the poleward lying air. Whether this is the correct explanation or not, the fact remains that these two great belts of high pressure exist at latitudes 37 deg. north, and 35 deg. south. Were it not for the rotation of the earth this simple cause of differential heating would set up a very simple circulation of southerly winds blowing from the southern high pressure belt to the equator, and northerly high level winds blowing from the equator back to the top of the high pressure belt. The rotation of the earth leads to deflection, as explained by Ferrell. For example, in the Southern Hemisphere, the trade winds, instead of blowing from due south, become deflected to the left, and so constitute the south-east trade winds. Similarly, the air which has soared to a high level over the equator, as it moves poleward, is deflected to its left, that is, in an easterly direction, hence the southern anti-trade wind blows from the north-west to the south-east. So far, atmospheric circulation seems simple. Before we pass on to the less understood portion, it may be added that the differential heating of the equatorial as compared with the extra tropical air-belts, is further emphasized by the fact that there is more aqueous vapour present near the equator than in the extra

tropics, and this aqueous vapour being a good absorbent of heat increases the differential heating at the equator. Further, the atmospheric pressure at the equator is lessened by the presence of this aqueous vapour, the largest amount found anywhere in the earth's atmosphere, and aqueous vapour, being lighter than air in the proportion of 1-1.623 for similar temperatures and pressure, the aqueous vapour at the equator has a greater ballooning or flotation effect there than elsewhere. Both these causes then, together with the adiabatic expansion of the equatorial air, contribute to produce those convection currents which are the prime cause of the trade winds and of the anti-trades.

We can now follow the atmospheric circulation on the poleward side of the high pressure belts (or "horse latitudes," as they are popularly called).

First of all, it may be explained that not all the air which returns to the earth's surface at the base of the high pressure belt flows back again towards the equator. A large part of it divides off and blows polewards, but like the anti-trade winds, from which it has been derived, it, too, undergoes a deflection to the left, and becomes at first the north-west, then west-north-west, and ultimately a westerly wind. These winds, known as the "Roaring Forties," are the most persistent and violent winds in the world. The position of their northern boundary varies a good deal with the seasons, but may be described as approximately nearly coincident with the south coast of Australia. The exact mean southern boundary is as yet unknown, but it may be stated that it extends at times down to about latitude 60 deg. south. It is here that there has been proved to exist that great gully or gutter in the earth's atmosphere[1] forming a complete channel around the earth from east to west. The Roaring Forties blow into it from the north, the blizzards from the Antarctic blow into it from the south. A possible reason for its existence will be suggested presently; but we must first follow the probable course of the earth's atmosphere at a high level from the southern anticyclone belt to the south pole. Very little, indeed, is known as yet about this subject, chiefly on account of the fact that nearly the whole of this area is covered by water. Hence the great importance of meteorological observations such as those that are being taken now in the sub-Antarctic at Macquarie Island, by Mawson's Australasian expedition, and in the Antarctic by Filchner, Scott, and Mawson. We do, however, know something of the circulation of the upper atmosphere in the northern hemisphere, though even there there is still much difference of opinion as to the directions of movement of the upper air currents. We have occasionally actual experiences such as the

[1] This is called by Hann "Die Rinne" or "Die Luftfurche".

following giving us an indication of the circulation of the upper atmosphere:—At the great eruption of Mount Pelée, in Martinque and La Soufriére, in St. Vincent, in the year 1902, vast quantities of volcanic dust were projected to heights of over 20,000 feet into the higher atmosphere. The trade wind current is there no more than about 13,000 feet in thickness, so that above that level the dust entered the great stream of the anti-trade wind, blowing from south-west to north-east, in that part of the world. This dust was later identified on the surface of the snows of the Swiss Alps, in Canton Lucerne, and it is thought to have been traced as far as Hamburg, in Germany. This proves that the anti-trade wind does not cease at the northern belt of high pressure, but moves poleward, perhaps as far as Hamburg. Further observations in the northern hemisphere, by means of nephoscopes, *ballons de sonde*, &c., prove that there is a steady drift taking place of the cirrus clouds in the higher atmosphere, from southwards, or west-south-west, towards north-east, or east-north-east. These poleward-flowing high-level air currents from the high-pressure belts form a stupendous whirl, or aerial mälstrom, over the north polar area. In the same area the surface winds are westerlies, blowing spirally polewards. Thus we see that two immense air currents, in the northern hemisphere, spiral inwards towards the north pole. Unless there were some kind of counter-current, obviously there would very soon be an intense congestion of air at the north pole, and equatorial regions would be robbed of their atmosphere. There must, therefore, be some great counter-currents which restore the air from the pole to the equator. How this restoration is accomplished is certainly a great crux of modern meteorology. There are several possible explanations. The first is that the surface westerlies ascend in the north polar region in a huge slowly moving cyclone until they meet the high level westerlies descending over the north pole in a great inverted cyclone. The air from these two cyclones is assumed to meet at an intermediate level, and is thought then to flow backwards towards the high pressure belt, and in its passage has to force its way past the high level poleward current above and the low level poleward current beneath.

Of late years Dr. Shaw, the Director of the Meteorological Office in London, has suggested that there is little trace of any effective circulation of the atmosphere between the latitudes of the high pressure belts and the poles. He adduces in evidence of his view that the westerly winds on the polar side of the high pressure belts in either hemisphere blow for the most part from almost due west to nearly due east. This, he maintains, is the case both at the surface of the earth and also in the higher atmosphere, as evidenced by the drifts of the cirrus clouds. On the other hand,

in their latest works on meteorology, Milham and Moore, following Hann, show a spiral movement for the poleward seeking air as it moves from the high pressure belts. The fact that volcanic dust, as that from the great eruption of Krakatoa in 1883, after rising to a height of what is estimated to have been over 23 miles, became distributed practically over the atmosphere of the whole world suggests that probably poleward seeking and spirally moving air currents actually exist. According to Dr. Shaw's theory, there might still presumably be a slow interchange of air between the poles and the high pressure belts through the "passing-on" action of the Antarctic cyclones, just as a football is passed to and fro in a series of "scrums" on a football field. As far as the observations of the members of the Shackleton expedition extend, the high level circulation near the South Pole from the Antarctic Circle polewards has a distinct southerly component of movement After encountering intensely severe westerly gales on the *Nimrod* we suddenly emerged into clear weather near the Antarctic Circle, and for two days obtained good observations of cirrus clouds floating at an altitude of between 15,000 and 18,000 feet. These were moving towards a direction between S.E. and E.S.E., at an approximate speed of about 20 miles an hour. At our winter quarters at the foot of Mt. Erebus, we were almost exactly due west of that mighty active volcano, so that we were in an admirable position to see, by means of the deflection of the great steam column at its summit, whether or not there was any southerly component in the atmosphere at a level of over 13,000 feet. Normally, when the volcano was in only mild eruption, the steam cloud was slightly deflected to the north of east by an air current blowing from off the high plateau.[1] On the whole this wind, therefore, appeared to be an equator-seeking wind, part of a return current from the pole towards the belt of the Antarctic "lows." At the same time it may have been merely a local wind blowing from the high plateau to the Ross Sea, which is not only a low-lying area, but an area of low pressure also. Now comes a point which appears of special interest. On the 14th June, 1908, an eruption of considerable violence broke out from the summit of Erebus. Vast volumes of steam rose in globular masses so rapidly above the active crater that in about a couple of minutes they attained an altitude of from 5,000 to 6,000 feet above the summit of the mountain—that is, they rose at the rate of about half-a-mile a minute. The spectacle was truly sublime; but the most thrilling moment of all was when, as the top of the steam cloud rose above the 15,000-ft. limit, it was suddenly deflected by a very powerful and rapid overhead current having a very decided southerly component. Long wreaths of white vapour were quickly trailing out

[1] The direction of the *sastrugi* (wind-eroded furrows) on the plateau to the west of the Royal Society Range, as observed by Scott, are from W. by S., or W.S.W., to E. by N., or E.N.E.

in the path of this current in a direction which appeared to be approximately from W.N.W. to E.S.E. Here, then, was a possible outward and visible sign of the existence of a vast aerial mälstrom, which may have been circling around the Pole for untold millions of years, but the absolute existence of which had probably never before been revealed to man until this occasion, when we had the unique privilege of witnessing it. It was a sight that truly filled us with wonder and with awe.

On four other separate occasions—17th July, 1908; 2nd August, 1908; 31st August, 1908, and 13th September, 1908—we noticed precisely similar phenomena, so that there can be little doubt, in my opinion, that in this part of the world a great spirally inflowing whirlpool of air does really exist, and its centre appears, on other evidence, to be not far distant from the South Pole.[1]

The observations of Teisserenc De Bort, at Trappes, in France, and elsewhere in the Northern Hemisphere, together with those of other meteorologists, prove that there is a distinct down grade polewards in the atmospheric pressure at a height of 4,000 meters, and the calculations of Meinardus, as quoted by Hann, show that a similar down grade exists near the 2,000-meter level in the Antarctic.

Hann, in his admirable and inspiring work, *Handbuch der Klimatologie*, estimates that the Antarctic anti-cyclone, composed of the air sinking down to the earth's surface from the great cyclone above it, is normally not more than about 2,000 meters in thickness. These figures do not agree well with our observations near Mount Erebus, but it must be remembered that conditions there were abnormal on account of the presence, 50 miles to the west, of the vast chain of the Antarctic Horst trending approximately in a north and south direction, and tending to deflect upwards to an abnormal height, the winds blowing nearly at right angles to it off the high polar plateau.

Our observations showed that normally the wind off the plateau of South Victoria Land blew steadily at Mount Erebus, between an altitude of about 5,000 feet and about 15,000 feet, in a nearly east direction, more often inclining to the north than to the south of east. Below the level of 5,000 feet, the air would normally be calm or moving south, as the result of a gentle northerly breeze from off Ross Sea. Above the 15,000-ft. level, as revealed to us

[1] Supan thinks that the Antarctic anticyclone has its heavy point (Schwer punkt) in the Eastern Hemisphere. Lockyer thinks that its centrum is near 180° E. long., and somewhat away from the Pole.

by the steam column from the eruptions just described, the great current of poleward-seeking air was reached, and this extended upwards to vast heights, probably of the order of at least 25,000 feet.

If these conclusions are correct for the Mount Erebus region, the high level plateau wind, which may there be considered the abnormal anti-cyclone, locally deflected eastwards into Ross Sea, is thus no less than 15,000 feet in altitude at its upper limit, that is over 4,500 meters instead of Meinardus' estimate of 2,000 meters. This does not invalidate Meinardus' conclusions in regard to the upward limit of the normal anti-cyclone, such as that of Kaiser Wilhelm II. Land. At Erebus, there are two abnormal conditions affecting the height of the anti-cyclone—(1) the upward deflection of the normal anti-cyclone by the Antarctic Horst; (2) the upward deflection due to the high volcanic cone of Erebus.[1]

A feature of great interest in the atmospheric circulation of the Antarctic revealed itself to us at the time of the coming on and development of the great blizzards. We were able to distinguish between high-level blizzards and low-level blizzards, the former often blowing hard at a level of 6,000 feet about over our heads, while below all was calm. A premonitory symptom, especially in winter time, of the coming on of an impending blizzard was the swinging around of the great rolls of alto-cumulus clouds from a N.-W. and S.-E. to a N. and S. direction. Meanwhile, the summit of Mount Discovery, over 60 miles to the S.S.W., would be capped with cloud. Later, after an interval of perhaps a few hours, and usually, but not always with a low barometer, a heavy roll of a dense low-lying cloud, something like the roll that precedes the southerlies along our Australian coasts, would be seen in the south. This rushed upon us at such a rapid rate that, even when only a half-a-mile distant from our winter quarters, we had only just time to run for shelter before the full fury of the blast struck us. It was difficult to see, as the blizzard progressed, exactly what was happening in the atmospheric circulation at the higher levels, on account of the deneness of the drift snow. By continuous careful observing, we occasionally caught glimpses of the top of Erebus

[1] On our journey in 1908-9 to the edge of the South Magnetic Pole area we observed that for the last 50 miles of our march before reaching lat. 72° 25′ S., long. 155° 16′ E., the chief sastrugi trend from due S. to N. Thus the normal anticyclone wind blows there first from S. then backs to the S.E., leaving weaker broad-topped "ramp" sastrugi trending from S E. to N.W. Recently, since this address was read, the returning members of Dr. Mawson's Australasian Antarctic Expedition report that at Adélie Land, and for 300 miles to the S.E. of Dr. Mawson's base there, at the head of Commonwealth Bay, the chief sastrugi trend nearly due S. and N., crossed by smaller "ramp" sastrugi trending from about S.E. to N.W. The average speed of the wind throughout the year 1912 at Adélie Land was no less than 48 miles per hour. This S to N. direction inclining towards the coast into a direction a little E. of S. and W. of N. may be looked upon as probably the normal one for the Antarctic anticyclone.

and its steam cloud, and it was clear to us then that the part of the atmosphere visible to us, instead of being divisible into three parts, as during calmer weather, now appeared to consist of only two air currents moving rapidly in opposite directions, namely, the south-easterly blizzard, blowing at about 50 to 60 miles an hour during the fiercer gusts; and the poleward-seeking high-level current. It was always noticeable that, as the blizzard developed in intensity, this latter current veered continuously more and more south, until at last it became a north to south wind.

Another very interesting fact which we noticed during the progress of blizzards was that the high-level wind blowing polewards decended lower and lower as the blizzard progressed, first truncating the top of the steam column of Erebus, and then slicing it off section by section until at last the column was cut off short at the edge of the crater. Later, one could see, by the ripping off of the snow-drifts by this northerly wind, that its lower limit had descended about 1,000 feet below the summit of the volcano. In other words, during the most severe blizzards, the whole of the poleward-seeking system of air streams appeared[1] to sink vertically by an amount equal to about 3,000 feet.

Another feature of interest was that, at the conclusion of the blizzard, while the air had become calm at sea-level, at our winter quarters, at a higher level the air would be moving rapidly northwards, and in a short time this high-level southerly air stream would spread up to and even over the top of Erebus; and then the great steam vane, some 20 to 30 miles in length, attached to the top of Erebus, would at once swing around from south through east to north, until little by little the normal plateau wind resumed its old direction from W. by S. to E. by N., and reclaimed control of the Erebus steam vane, forcing it back into an E. by N. direction.

We now pass on to a most important question of great significance. In most parts of the world, with the exceptions of the North and South Poles, the barometric pressure is greater in winter than in summer, for as the cold of winter approaches, the air in contact with the cold sea or cold land becomes chilled, and so is rendered denser in winter than in summer; but at the Poles in winter the barometric pressure is lessened. Now, in whichever hemisphere it happens to be winter, it is the experience that in that

[1] This sinking does not probably imply that the whole atmosphere during a blizzard is thinned to the extent of 3,000 feet, as, if that were so, the barometer would fall greatly during a blizzard, which is not the case. There may be some actual thinning, but the phenomenon appears to be chiefly due to the high level polar cyclone successively affecting lower strata of the atmosphere during the progress of a blizzard.

hemisphere, atmospheric circulation is considerably accelerated. The reason for this will at once be apparent from a study of the curves shown in Fig. 3.

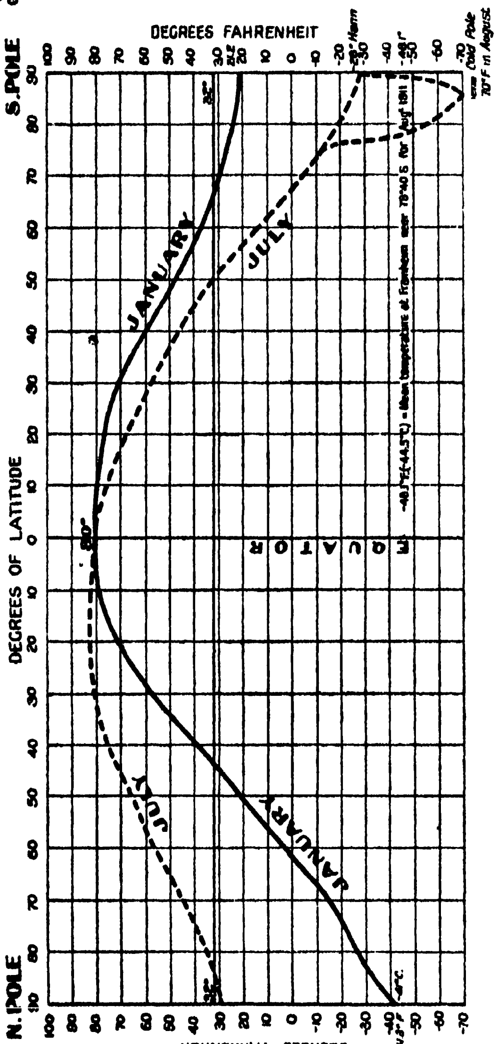


FIG.

These I have taken chiefly from Hann, constructing the remainder of the curves to the right from 60 degrees south to the South Pole from data obtained by recent Antarctic expeditions.

It will be noticed that the temperature at the Equator scarcely varies at all between summer and winter, remaining about constant at about 80 degrees Fahrenheit.

Now, at the North Pole in summer, the mean temperature is about 30 degrees F., whereas in winter it is minus 41.8 degrees F. Obviously, then, the difference in temperature between the North Pole and the Equator in winter is greater than that in summer by no less than 71.8 degrees F.

This steeper grade of the isotherms in winter is accompanied by an equally steeper grade of the isobars in winter than in summer. This obviously is the reason for the acceleration of atmospheric circulation in the Northern Hemisphere during the northern winter. Similar phenomena have been observed in the Southern Hemisphere. There, at the South Pole, the temperature at the end of January is thought to be about 21 degrees F., and in July it is considered to be about minus 28 degrees F., when reduced to sea-level. Of course, as the South Pole itself is not at sea-level, but at an altitude of about 10,260 feet, the actual mean temperature there in July may be as low as minus 70 degrees F. At the South Pole, therefore, as at the North Pole, there is a considerably steeper isothermal, and consequently isobaric grade in winter than in summer. The isotherms and isobars are particularly steep along the main Antarctic shore-line, for the obvious reason that, whereas in winter the temperature a few miles inland may be minus 30 or 40 degrees F., the temperature of the open ocean, a few miles to the north of the shore, does not fall below 28 degrees F.—a difference of temperature of no less than 58 to 68 degrees F. in a distance of 20 miles or less.

One can easily understand why, with these abnormally steep barometric grades, and the general dome shape of the Antarctic Continent, with its almost universal seaward slope, the blizzard wind develops such intense speed near where land and water meet.

The questions now suggest themselves—(*a*) Why is the atmospheric pressure lower at the poles in winter than in summer, and (*b*) why, generally, is the atmospheric pressure so much less towards the poles than elsewhere, particularly in the case of the South Pole? Hann suggests that the former question is to be answered on the lines that the phenomenon is due to some dynamic effect to be connected with the increased rapidity of circulation of the atmosphere in winter time.[1]

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[1] His remarks are of such importance that they are quoted here in full:—

*Dr Julius Hann. Handbuch der Klimatologie. Bd. III., s. 601*

"Im amerikanischen Polargebiet begegnen Wir der interessanten Erscheinung, dass das Minimum der Temperatur mit einem Minimum des Luftdruckes zusammenfällt. Obgleich über Nordgrönland und Melville Island ein Kältepol liegt (mit – 35 bis – 40° C.) und die Erstreckung und Machtigkeit der kalten Luftmassen daselbst vielleicht grösser ist als über dem allerdings intensiveren asiatischen Kältepol, sinkt doch der Luftdruck und erreicht im Januar ein Minimum. Wir müssen dies wohl auf dynamische Ursachen zurückführen; die Druckabnahme gegen das Zentrum des Polarwirbels kommt dann trots der Störungen der normalen Druckverteilung auch an der Erdoberfläche zur Geltung, was in Asien wegen der grossen Luftdruckanhäufung in den untersten Niveaus, die namentlich auf orographische Bedingungen zurückzuführen sind, nicht möglich ist. Uber den gleich-förmigeren Flächen des amerikanischen arktischen Gebietas greift der Polarwirbel bis gegen die Erdoberfläche hinabdurch.

Presumably, increase in centrifugal force may partly explain the lower barometric pressure in Antarctica in winter as compared with summer, but are there any other contributing factors? Certainly the flotation effect of aqueous vapor cannot assist, inasmuch as obviously in winter, when the air is colder, there would be less aqueous vapor along given latitudes than in summer, when the air is warmer. The vapor factor would, therefore, tend to increase pressure in winter, rather than to diminish it. I would venture to suggest very tentatively that another factor contributing to a lessening of atmospheric pressure in winter may be of the nature of an actual thinning of the atmosphere.

The question appears to be one of hydro-dynamics, and may be rather intricate. The suggestion may be made that the thinning is brought about by a lag in the movement of the upper atmosphere as compared with that of the lower. For example, in the case of the blizzards, it would appear that the masses of cold air over the Antarctic slip away from underneath the air of the circum-polar whirl at such a rate that the inflowing air from the north is unable to overtake the demand for air near the Pole to take the place of what has been lost in the blizzard. This is perhaps the explanation of the phenomenon of the sinking of the upper air currents from an altitude of 15,000 feet to that of about 12,000 feet at Erebus during the progress of a severe blizzard.

As regards (*b*), the answer usually given to explain the diminished atmospheric pressure at the Poles as compared with that at the Equator is that it is due to the increase of centrifugal force of air masses seeking to conserve their moment of momentum as they move polewards. This explanation must be provisionally accepted, but it is not necessarily the only explanation. The lower atmospheric pressure near 60° S. as compared with 60° N. is chiefly due probably to the greater preponderance of sea over land in the Southern Hemisphere near that latitude as compared with the northern, and the consequent less frictional resistance to wind currents, in 60° S., as compared with 60° N.

Possibly here, too, there is a hydraulic factor tending to locally thin the atmosphere during the normal out-rush of the anticyclonic wind as it spirals first in a N. by W., and eventually in a W. by N. direction. That gigantic refrigerator, the Antarctic Continent, may, during blizzard time or in the itnervals between the blizzards, throw air off its shoulders at such a rapid rate that the incoming air is unable to overtake the demand, and so seldom, if ever, comes into gravitative adjustment. This assumed thinning of the atmosphere by lessening the thickness of the earth's air blanket in the direction of the Antarctic Circle and the Pole would tend to increase the cold in those regions by allowing heat to escape more rapidly where the earth's aerial clothing is thin than where it is thick. This suggestion is, of course, purely speculative, but the

great fact remains, of which use will be made presently, that the more rapid the circulation of the atmosphere becomes from the Pole to the Equator, the more is the atmospheric pressure in the neighbourhood of the Pole lowered. Consequently, if any factors which make for the acceleration of the atmospheric circulation are at any time increased, the barometric pressure at the Poles will be lower than ever, and the atmosphere there may become thinner than ever. Such factors will be shown in the sequel to have probably existed in the South Polar Region in Permo-Carboniferous time.

We may now pass on to another very important feature which is indicated by the nature of the curves, and that is that the North Polar summer is considerably warmer than the South Polar, and the North Polar winter at sea-level considerably colder than the South Polar winter at sea-level.

The following reasons suggest themselves to me as an explanation of this important fact:—First, the superior cold of the North Polar winter as compared with the South Polar winter, at sea-level, is probably due to several factors, but the chief factor is this—In the Northern Hemisphere the proportion of land to sea is much greater than in the Southern Hemisphere. On account of the much less specific heat of land than water, it follows that, as winter approaches, the great continents around or outside of the Arctic Circle radiate heat very rapidly and fall below freezing point much earlier than does the sea in similar latitudes in the corresponding winter months in the Southern Hemisphere; if, indeed, the sea in such latitudes as lie north of the Antarctic Circle ever freezes over at all.

Next, we find that in the coldest month of the Northern Hemisphere—January—not only is the whole of the Arctic Ocean frozen, but vast areas of North America, Northern Europe, and Siberia, including Mongolia and China as far south as Corea, are enveloped in snow. This area of earth surface, including sea ice, below freezing point in winter in the Northern Hemisphere may be estimated at approximately from 15 to 20 million square miles; whereas in the Antarctic, inclusive of the narrow rim of sea ice which forms during the winter, there can never, under existing conditions, be much more than about 5,000,000 square miles under ice. The central parts of the Antarctic Continent can nowhere be more than about 1,000 miles distant from the nearest open water, and the Anarctic Continent at this distance is entirely surrounded by water, the temperature of which is about 30° F. The steep isobaric grade, as already explained, leads to a rapid interchange, especially in winter time, of relatively warm air from over the ocean with intensely cold air lying over the Pole.

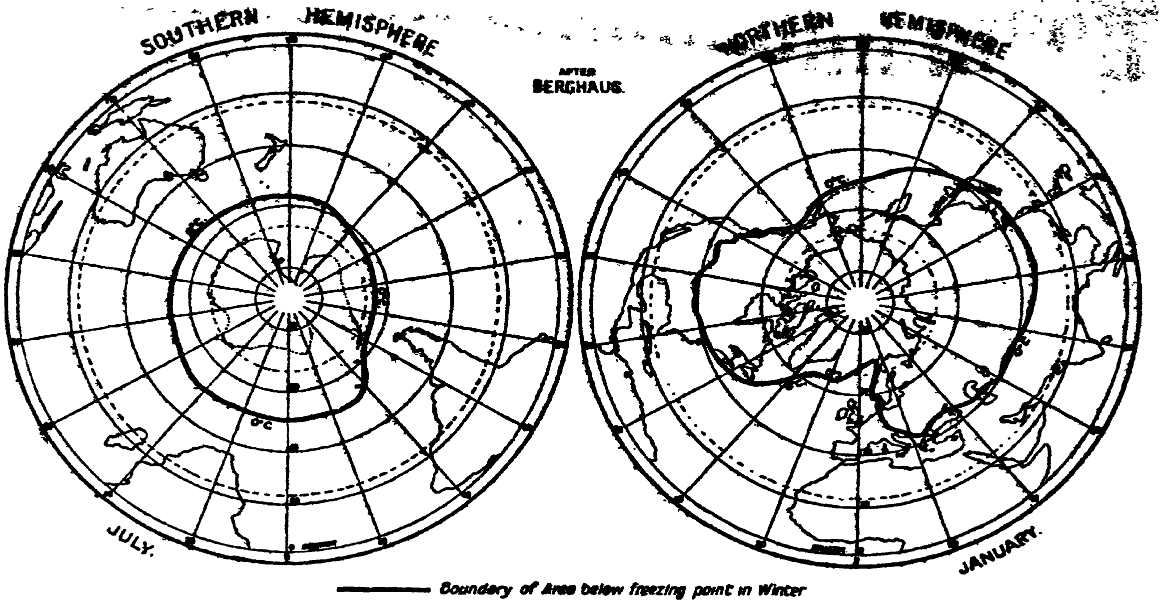


FIG. 4.

Map showing the much larger area below freezing in Northern Hemisphere Winter than in Southern Hemisphere Winter.

Conditions are very different in the winter of the Northern Hemisphere. Points lying about midway between the North Pole and Verkhoyansk, in Siberia, are distant, at least, 2,000 miles from the nearest point on the earth's surface where the temperature is above freezing. The vastly increased size of this mass of cold air in the north as compared with that in the south, and the comparative absence of convection currents from relatively narrow open seas, is probably one of the chief causes of the lower temperature of the North Pole as compared with the South Pole during their respective winters.

Next, we have to account for the relatively warm summer of the North Pole as compared with the cold summer of the south. The reason for this is even more obvious. There is a great ocean, the Arctic Ocean, at the North Pole. At the South Pole there is a great high continent. As spring passes into summer near the North Pole, the ice of the Arctic Sea breaks up, wide leads open, exposing belts of sea water, which then transmits its heat by convection to the atmosphere. Consequently, during the Arctic summer the temperature rapidly rises, until in July, the warmest month, it is actually about 30° F.—approximating to the temperature of the sea water at the North Pole. On the other hand, in Antarctica, no important convection of heat by ocean currents is possible on account of the existence of this large mass of high land almost concentric with the geographical pole. The great height of the land—towards the centre over 10,000 feet in height—induces a constant low temperature inland, so that even in midsummer, at the South Pole, in December and January, it is constantly from −15° F. to −25° F.[1] This cold air, as it blows outwards towards the coast, descends to sea-level, and though in its descent it becomes slightly warm, owing to the Föhn effect, is not really raised to the ideal temperature required by the Föhn law, as it is continually radiating its heat upwards in the process of its flow towards the sea. Thus the surface at the Pole is continually kept considerably below thaw point, even if that altitude is reduced to sea-level. At the actual Pole, according to Amundsen's observations, it never thaws. The snow there is absolutely devoid of the slightest trace of stratification. He ascertained this when erecting the tent pole. It was found that the pole could be driven with great ease to a considerable depth into the snow, which was of uniform softness throughout. It is only on the extreme edge of Antarctica that, even in summer, any thaw takes place. Consequently, there is a complete dearth there of all the higher forms of plant life, in fact, of all plant life, with the exception of a few algæ, besides dwarf mosses, lichens, diatoms, and bacteria. On the other hand, in the Northern Hemisphere,

[1] These are only rough estimates based on Amundsen's and Shackleton's observations.

in circum-polar lands, like Greenland, Grinnell Land, Grant Land, &c., as soon as the breaking up of the ice exposes the sea surface, the air temperature becomes raised to thaw point, and during the maximum heat of the day actual thaw takes place. Where rock or earth projects through the mantle of ice or snow, on account of the low specific heat of rock, especially black rock, of which there is much in Greenland, the thaw proceeds rapidly. Large areas of land surface are laid bare; saxifrages, gentians, and a considerable variety of Arctic plants spring up and flower in the open patches amongst a low boskage of dwarf birch, dwarf willow, &c., and, wherever conditions are favorable, the reindeer moss flourishes. As a result of all this vegetation, we find herbivorous animals, such as the reindeer, the musk-ox, the caribou, &c., are able to exist in large herds. This, in turn, has made is possible for man to live in the vicinity of these herds in defiance of the intense rigour of the climate in winter. Hence these remarkable conditions of vegetation, stocking with higher mammalian life, and peopling with mankind, so different from the conditions of Antarctica, have been brought about in the Arctic chiefly through differences of geographical conditions, preponderance of land over sea near the Arctic Circle area, and the existence of an ocean partially open in summer around the North Pole.

Surely here we have an immensely important argument in favour of distribution of land and water and relative elevation of land, proving a very important factor in the control of climate!

We may now very briefly glance at a few salient features in the meteorology and climate of Australia. For details, those interested are referred to the much needed work about to be published on the climate and weather of Australia by Mr. H. A. Hunt, the Federal Meteorologist, and Mr. T. Griffith Taylor, the Federal Physiographer. To both of these authors, who have given me the privilege of perusing the manuscript of their work now going through the press, I am deeply indebted for much information. The following facts in regard to the climate of Australia may be specially emphasized:—

First, Australia is so situated in latitude ranging from 10 deg. S. to 43 deg. S. that its southern portion is well within the annual range of the southern anticyclone or high pressure belt. The sun reaches the southern limit of its annual range of 47 deg. at the Tropic of Capricorn, 22nd December. The high pressure belt follows the sun with a lag in point of time of about three or four weeks. The annual swing of the high pressure belt is from Lat. 30° to Lat. 42°.

Australian weather is controlled by, for the most part, three strings or belts of atmospheric eddies; first, the tropical lows developed in the trade wind area. These lows are commonly spoken of as the monsoonal lows. Secondly, south of the former, is the great belt of moving anticyclones. Here it may be mentioned that a former president of this association, than whom Australasia has never produced any worker more devoted to the

study of science for its own sake, nor one who did a greater and more lasting work in organizing and co-ordinating Australian meteorology—the late Mr. H. C. Russell—was the first to demonstrate conclusively that these anticyclones move along definite paths from west to east. The mean position of the belt of moving anticyclones is about 35 deg. south latitude. South of latitude 40 deg. is another belt of low pressure eddies, either the northern part of huge Antarctic eddies, or secondaries, lying on their northern fringe.

All these three belts of eddies travel from west to east. As regards their speed of movement, the tropical or monsoonal lows travel about 199 miles per day. The greatest number appear to occur in September, and the quickest movement is developed in October.

The sub-Antarctic lows in June, 1910, averaged about 360 miles per day off the Leeuwin, while over the Bight they attained a speed of about 550 miles a day, and over Tasmania about 360 miles a day.

The centres of high pressure travel at about the same speed as the Antarctic lows south of the high pressure belt. As the air is blowing from the southern side of the anticyclone belt polewards, it is deflected to the left, and becomes part of the Roaring Forties winds; the Antarctic lows are eddies developed within these winds. As these winds are blowing with a slight southerly component, they consequently are moving from warmer towards colder regions. Sooner or later, their dew point is reached, and a dense cloud belt results, like that which is so persistent over Macquarie Island, the Auckland and Campbell Islands, Bounty Island, the Antipodes, and the Snares, and which gives rise through its constant cold moisture to the development there of such extensive beds of peat.

It is hard to overestimate the importance of Macquarie Island as a permanent meteorological station for the very important study of these secondary Antarctic lows, as well as for understanding the whole theoretical circulation of the atmosphere. Its wireless meteorological station, established there by Dr. Mawson's Australasian Antarctic Expedition, is at present supplying daily weather reports to Australasia of very high value for the correct interpretation of Australian and New Zealand weather. This island is ideally situated for the study of the much vexed question of atmospheric circulation in just that part of the belt of the great westerly wind current, in which are generated those secondary Antarctic lows which so profoundly affect Australasian weather. Being near the same latitudes as the meteorological observatories established by the enterprise of the Argentine Republic at the Falkland Islands, in the Strait of Magellan and Drake Strait, and the normal direction of weather movement being nearly straight from the Falkland Islands to Macquarie Island, the latter island should yield invaluable data as to the speed of

transit, &c., of these sub-Antarctic lows. It is to be hoped that this Association will see its way to strongly recommend the maintenance by the Commonwealth Government of this wireless and meteorological station on a permanent basis[1]. If this scheme is carried out I am assured that the comparatively small expense, perhaps £800 to £1000 a year, will be recouped tenfold in actual economic benefit to the Commonwealth, and thus the good work that this Association has done in giving such timely aid to Dr. Mawson's expedition will live, let us hope, and benefit humanity for all time.

It is thus to Macquarie Island, the great potential meteorological link between Australasia and Antarctica, that I wish specially to invite your attention to-night. As already explained, observations in Antarctica have shown that on the whole there is strong evidence for the existence of a high level Antarctic cyclone, at all events in the Ross region of East Antarctica.

At the base of this lies a large mass of very cold, dry, and therefore heavy air, inert and stagnant for the most part, but locally crumbling away at its base under its own pressure from time to time, and giving rise to those fierce outrushes of air, the blizzards. At King Edward VII. Land these are easterly winds, near Mount Erebus, south-easterly, from the South Magnetic Pole area to Adélie Land southerly, at Kaiser Wilhelm II. Land easterly. Although sometimes they persist as a distinct entity across the belt of the westerlies, and may even perhaps reach the shores of New Zealand, they probably mostly expend their energy in reinforcing the S.-W. or S. limb of one of the many violent cyclones which have their centres near the zone of lowest pressure ("Die Rinne") in the belt of westerly winds between the Antarctic circle and the parallel of 60 deg. S. In this belt of low pressure the air appears to soar aloft in gigantic eddies. Why it should so soar is difficult to understand. It is thought that the air in the westerly belt, increasing its speed in order to conserve its moment of momentum as it spirals around the earth southwards, develops great centrifugal force which tends to swell up a ring of air (like the protuberant belt "der Wulst") of the equator, but formed mechanically, not thermally like the equatorial "Wulst." Ascending vapour, converted into rain or sleet, sets free latent heat, which further encourages the rising of the atmosphere in local domes upon the swollen air ring of latitude 62 deg. S. Thus at a high level above "Die Rinne" there is probably an increased atmospheric pressure as compared with the pressure at a similar level over the South Pole and over the Southern Anticyclone Belt. Hence it is probable that there is

[1] The Government of the Dominion of New Zealand, with the most emphatic support of the proposal by their Meteorologist, Mr. Bates, have subsequently joined this Association in strongly urging the Federal Government to take over this wireless and meteorological station, and maintain it on a permanent basis. Since this address was read the Commonwealth Government have agreed to take over this wireless meteorological station for a year, and we may hope that this step is preliminary to its permanent maintenance by the Government.

not only a flow from the vault over the low pressure ring polewards, but also a high level outflow northwards from this vault to the Southern Anticyclone Belt. These suggestions as to the circulation of the atmosphere in the Southern Hemisphere are illustrated in Fig. 5, from which the great importance of Macquarie Island as a site for a permanent meteorological station at once becomes apparent. The scheme which suggests itself to me as to atmospheric circulation in the Southern Hemisphere is illustrated in the rough diagram below:—

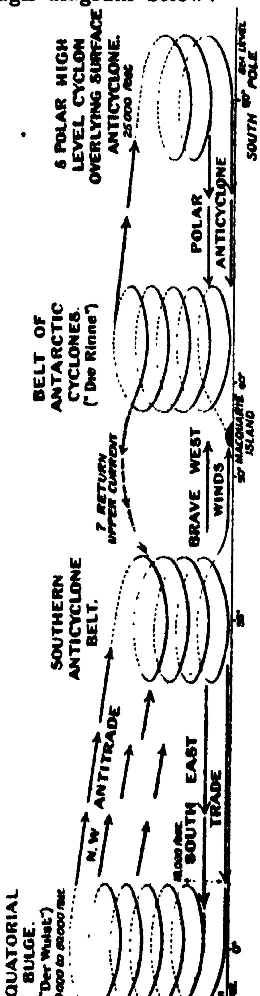


Fig. 5.

Section showing possible circulation of atmosphere between Equator and South Pole, illustrating importance of Macquarie Island as a Meteorological Station.

It will be noted from Fig. 5 that it is the nature and direction of the high level circulation between the Southern Anticyclone Belt and the Antarctic cyclones that is most in doubt.

*Ocean Currents.*—A few notes may here be given as to the great importance of ocean currents in Australasia. in regard to their effect on climate, and the modification of Australian climate which would follow from a stopping of these currents by a greatly extended Antarctic like that of Permo-Carboniferous time.

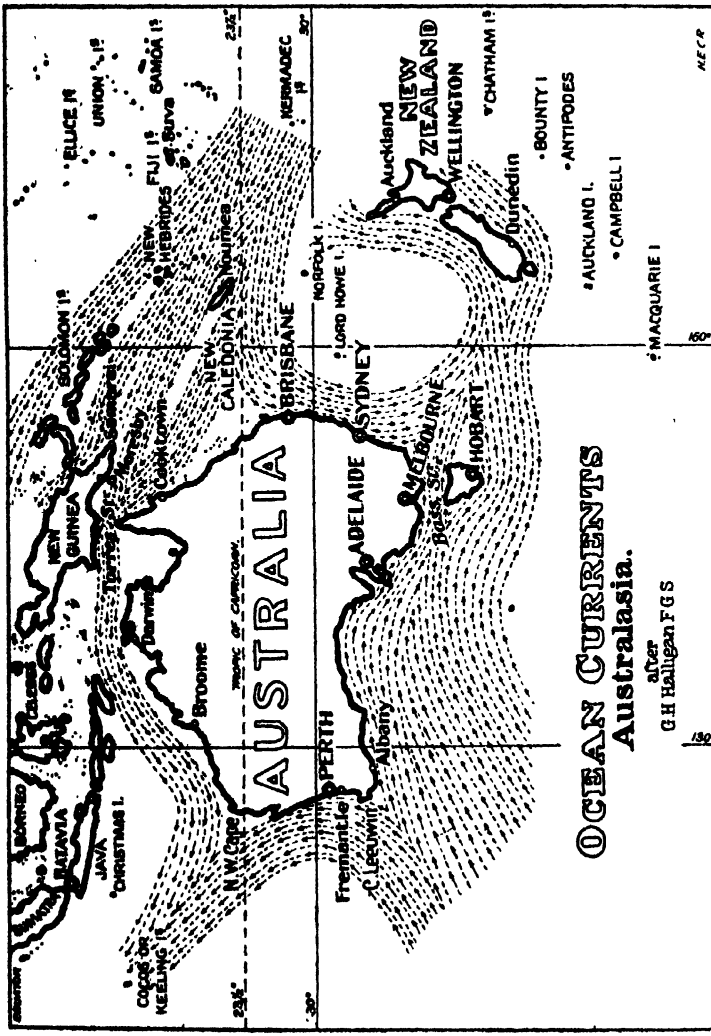


FIG. 6.

The subject of the ocean currents off the Australian coast has been specially discussed in an able paper by Mr. G. H. Halligan.[1] Those interested are also referred to the carefully prepared account of the East Australian current, called by him the Notonektian current, by Mr. Charles Hedley.[2] Professor J. W. Gregory, late of Melbourne University, has also written on the climate of Australasia in reference to its control by the Southern Ocean.[3]

The accompanying map, the most complete and reliable to which I have access, is after Mr. G. H. Halligan (Fig. 6).

It will be noticed that on the map of the world showing ocean currents, the cold currents of the Southern Hemisphere are chiefly on the west coasts of the great continents, and the warm currents on the east coasts. These currents depend for their direction chiefly on the prevalent winds. The roaring forties tend to drive the cold water of the Antarctic up the west coasts. To this cause is due the Peruvian current, the Benguelan current, and the Western Australian or Humboldt current. Warm water flows down the east coasts of South America, South Africa, and East Australia, recurving from the east to west current set up by the trade winds.

Mr. C. Napier Bell, of New Zealand, called the attention of this society[4] to the very interesting fact that the temperature on the west side of New Zealand was quite an exception to the rule, for it is no less than 8 deg. to 10 deg. F. higher than that on the east coast. This is due to a recurving of the East Australian current, the current flowing eastwards from Gabo Island until it strikes New Zealand, when it is deflected northwards, thus raising the temperature along all the west coast of New Zealand. The current of Bass Strait in winter, when the centre of the high pressure belt is well north of the southern coasts of Australia, and consequently the westerly winds control the strait, sets strongly from W. to E.; but in summer, when the high pressure belt has moved down to the latitude of Bass Strait, and so the westerly winds are displaced southwards, the easterly current becomes very sluggish. In the Great Australian Bight the current is normally easterly. On the west coast of Australia the current sets north, and is a relatively cold current. The currents along the north coast of Australia are controlled by the trade winds, and are derived from the south equatorial current, which is probably somewhat checked or driven on shore in summer by the N.-W. monsoon.

*Past Climatic Changes.*—A study of these in detail would easily supply material for several addresses, and indeed they have

[1] Proc. Linn. Soc. N. S. Wales, New Series, Vol. xxxi., Pt. iii.

[2] *Ibid.* N. S. Wales, New Series, Vol. xxxv., Pt. 1, pp. 9-21.

[3] The climate of Australasia in reference to its control by the Southern Ocean. By J. W. Gregory, D.Sc., F.R.S., Melbourne, Whitcombe and Tombs Limited.

[4] Rep. Austr. Assoc. Adv. Sci., Christchurch, N.Z.

been so strongly marked in the past as to form a very interesting feature in the past physical geography of Australasia. Meanwhile a very brief summary must here suffice.

As regards the fluctuations of temperature in Australia in the geological past we owe it to the distinguished man, the late Director of the Geological Survey of Victoria, A. R. C. Selwyn, that traces of the most remarkable glaciation that the world has perhaps ever seen were discovered by him in the Inman Valley, near Port Victor, in South Australia. This discovery, the full significance of which was not appreciated at the time, was made in 1859. Mr. E. J. Dunn, the former head of the geological survey of Victoria, was the first who adduced conclusive evidence for the conclusion, suggested earlier by Richard Daintree, that in Victoria, at Bacchus Marsh, Derrinal, near Heathcote, and indeed distributed over a wide area there are glacial beds or tillites of Permo-Carboniferous age. Similar beds of the same age have been identified in New South Wales, and they have been discovered on a large scale by Mr. A. Gibb, Maitland, in Western Australia, where they extend right up to the tropics. They also occur in India, South Africa, Southern Brazil, and in the Argentine Republic. There can be little doubt, in view of the distribution on the earth of animal and plant life at this time, that an immense continent probably extended right across the Indian and South Atlantic Oceans as well as to Antarctica. This enormous land mass would in itself, by checking any warm poleward flowing ocean currents, produce great cold in the Southern Hemisphere. We should have had present winter conditions in the Arctic obtaining in the Southern Hemisphere also, but to a much intensified degree, and the cold would have been further greatly increased, as compared with present conditions in the Arctic, by the fact that there would be no relatively warm sea open in summer to modify the extreme rigour of this Permo-Carboniferous winter. There seems to have been a fall of temperature at this time of 15 deg. to 20 deg F. (8 deg—11 deg. C.). Possibly this great difference in the geographical distribution of land and water would in itself suffice to account in a large measure, though not wholly, for the extraordinary glacial conditions during Permo-Carboniferous time. An interesting recent discovery in this connexion is that made by Professor W. G. Woolnough of Permo-Carboniferous glacial beds with straited boulders at the furthest point north on the East Australian coasts to which glaciated boulder beds have been traced at Kempsey in New South Wales. One interesting feature of these beds is that they conformably underlie limestones in which the coral *Trachypora*, a contributor to the small reefs of the period, is well represented.

Next, in descending order, we find in the Cambrian period evidence of an extensive glacial age in temperate to sub-tropical latitudes. Probably the contemporaneous climate was 12 deg. to

15 deg. F. (7 deg.—8 deg. C.) colder than at present. The important discovery of the existence of an intense and extensive glaciation in Cambrian time revealed itself, after many years of indefatigable toil, to the distinguished South Australian geologist, whom it has been the privilege of our association to honour with the award of the Mueller medal, Mr. Walter Howchin. May I express on behalf of us all the heartfelt wish that he may be spared many years of active life to further enrich geological science with his discoveries. These glacial beds are presumably on about the same horizon as those described by Mr. Bailey Willis, near the head of navigation of the Yang-Tse, in China.

Lately Professor Coleman, of Toronto, has discovered evidence of a very extensive glaciation in the Huronian beds of Canada, to the east of the great lakes, about 750,000 square miles of the earth's surface in that neighbourhood being then under ice. So far we have not yet discovered traces of a glaciation of this age in Australasia. Then, of course, there is the well known evidence of the Pleistocene, and possibly in part early Pliocene, glaciation of both the Northern and Southern Hemispheres demanding a fall in temperature in the Southern Hemisphere of about 10 deg. F.

In regard to palæontological evidence of Cainozoic change of climate in Australia, I am indebted to Mr. Charles Hedley, of the Australian Museum, Sydney, for the information that the genus *Pyrula* at present has its southern limit along the east coast of Australia, at Newcastle. It is met with fossil in the so-called Eocene (possibly Oligocene or even Lower Miocene) beds of Table Cape, in Tasmania, some 600 miles south of its present southern limit on the East Australian coast.

Mr. F. Chapman, Palæontologist to the National Museum, Melbourne, has kindly furnished me with the following notes:—

> "The Janjukian (Miocene) climate (sub-tropical to warm-temperate).—Although many of the genera and even species of the Miocene Victorian fauna are still living, the general aspect is that of a much warmer climate than at present found in Southern Australia. There is abundant proof of this in the fact that the Janjukian types of mollusca must now be looked for in the Queensland coast fauna, and still farther northward.
>
> The abundance of large Volutes, as well as the occurrence of the genera *Harpa*, *Phos*, *Ancilla*, *and Cucullæa*, with many others, are strongly indicative of warmer coast-lines, some being peculiarly Indo-Pacific generic types. Specifically many of the fossils are closely related to Miocene forms found in in the Vienna basin, a deposit whose shells clearly indicate warm temperate to sub-tropical conditions. The *Lepidocyclina* of Batesford indicates a warm temperate sea, such as prevailed in the Tethys or Miocene mediterranean.

The large discoidal *Orbitolites*, once so common in the warm Tertiary seas of the Paris basin, are abundant in the Miocene greensands of the Victorian Mallee. It has now retreated to lower latitudes, being found in Shark's Bay, Western Australia, at latitude 26°, and off the Great Barrier Reef, Queensland, at about the same parallel.

The Kalimnan (L. Pliocene) climate (warm temperate to cold).—The *Limopsis beaumariensis* of the Lower Pliocene of Beaumaris, in Victoria, is closely allied to a Japanese species now found in lower latitudes. The presence of *Saxicava* and abundant *Natica* and *Tellina* indicate a considerable cooling down of the climate in this period.

Post-kalimnan (Late Pliocene and Pleistocene) climate (temperate to cold).—The brackish foraminifera of the Mallee indicate a further cooling down from temperate to cold conditions."[1]

This palæontological evidence implies a chilling of the waters in South Australian seas to the extent of about 6° to 7° F., and all this has taken place since Pleistocene time. In view of the fact that the *Arca trapezia* beds are about 15 feet above sea-level in New South Wales, it is suggested that perhaps these raised beaches may have formed during an interglacial epoch in late Cainozoic time. The melting off of a thickness of about 600 feet of ice in Antarctica would suffice to raise sea-level around Australia by about the above amount of 15 feet.

It is quite beyond the scope of the present inquiry to seek for all possible causes of these vicissitudes of climate, but the question as to whether variation in the geographical distribution in land and water will explain all the phenomena may be very briefly discussed.

In Permo-Carboniferous time, Chamberlain and Salisbury state[2] that a census a few years ago gave the known animal species of the carboniferous as 10,000, while those of the Permian were only 300,

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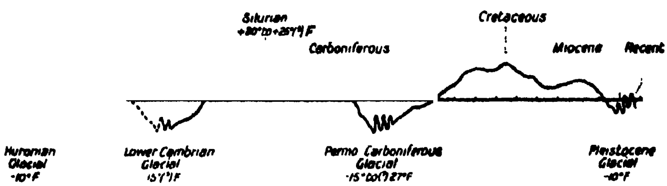
[1] Mr. Walter Howchin has called my attention to the following interesting facts in regard to the Post-Tertiary climate of Australia:—At the graving dock at Glanville, near Adelaide, and also at a drainage tank at Dry Creek, not far from the same city, are two well marked horizons carrying a geologically recent marine fauna The lower horizon is separated from the Lower Pliocene marine series by alluvial beds, without any evidence of marine conditions, 300 feet in thickness. Of the two Post-Pliocene marine horizons the lower at its upper limit is now about 25½ feet below high water at Glanville, and 6½ feet below high water at Dry Creek. It is separated from the upper, and evidently recent, marine horizon by a thickness of from 16–25 feet of freshwater beds, chiefly clays and sands. The upper marine deposit, a few feet in thickness, contains remains of a marine fauna identical with that in the neighboring seas, but the lower marine deposit, while all its species are recent, contains some forms not found now on the coasts of South Australia. For example, both at Dry Creek and at Glanville it contains an abundance of *Arca trapezia* and "the large warm-sea foraminifer, *Orbitolites complanata*." The latter species has now deserted South Australian waters, and has moved up to about 26° on the west coast of Western Australia, and up to about the same parallel of latitude on the east coast. As *Arca trapezia* is known to live at present in Australian waters as far south as Western Port, Victoria, its evidence of former warmer seas is not as strong as that of the above foraminifer.

[2] Geology, Stratigraphical, Vol. II., p. 642. Considerable additions have of late been made to the number of Permian species, but nevertheless the fact is still broadly as above stated.

or 3 per cent. Surely no possible arrangement in the distribution of land and water can reasonably account for the extinction of no less than 97 per cent. of the known species of animal life as we advance from the Carboniferous to the Permian. Surely some great cosmic cause, such as variation in the amount of the sun's heat received at different geological periods, must have contributed to bring about this remarkable result. Figure 7 shows the theoretical fluctuation of temperature at various geological periods. The time intervals are based on (1) assumed thicknesses for the geological formations similar to those given in Sollas' *Age of the Earth;* (2) an assumption that equal thicknesses of strata accumulated in equal time, obviously a very loose assumption.

CURVE SHOWING APPROXIMATE RANGE OF TEMPERATURE IN TEMPERATE LATITUDES IN GEOLOGICAL TIME




*Divisions on horizontal line refer to time based on relative thicknesses of strata formed at the various geological periods the latter after Prof. W J Sollas*

FIG. 7.

## SUMMARY.

From the evidence at present available, the following provisional conclusions may be deduced:—

That the reason for the great climatic and biological differences between the North and the South Poles respectively is mainly geographical, dependent that is on the present distribution of land and water, and the modifications which they introduce into the circulations of air and water in either Hemisphere.

In reference to the control of Australian weather at present by Antarctica, the existence of that large continent, with an average elevation of about 6,000 feet, acts as a great refrigerator in the Southern Hemisphere, and so causes extremes which would not otherwise exist between South Polar and Equatorial temperatures.

This factor tends to increase the rapidity of air circulation in the Southern Hemisphere, the acceleration being greatest during the winter months, when the isothermal, and consequently isobaric, grades between Antarctica and the belts of ocean to the north of it are steepest.

If the Antarctic Continent were to be entirely removed, and the Southern Ocean were continuous over the South Pole, Australia, and the Southern Hemisphere in general, would have a far more equable and more monotonous climate than at present. There would be none of those periodic fierce outrushes of blizzard winds which accompany the development of the Antarctic "lows" which so often profoundly affect Australian weather. With diminished energy of circulation in the Southern Hermisphere, it is probable that the rainfall of Australia would be also diminished. If this were so—and there seems no reason to doubt it—it is no exaggeration to state that part of the pastoral and agricultural wealth of Australia depends upon the existence of Antarctica in its present form.

While indirectly we probably owe some of our rainfall to Antarctica, we have less perhaps for which to thank her in the way of the icebergs which she annually launches into the Southern Ocean. But, after all, the danger to shipping from these bergs is comparatively small, and yet it is, of course, very desirable that accurate information may be recorded as to the exact route mostly followed by these bergs. Doubtless the increased rainfall which Antarctica probably gives us, through the vigorous stirring it imparts to the earth's atmosphere, enormously outweighs the small disadvantage of icebergs.

If Antarctica, instead of completely foundering, were to dissolve into an archipelago of low-lying islands, their summer temperature would be higher than that of Greenland and Grant Land, and, like them, the Antarctic islands would be clothed with hardy forms of plants, amongst which numerous flowers and mosses as well as trees, like the South American Fagus, would be included. With the advent of vegetation, the islands would become suited for herbivores, and, if later, this Antarctic archipelago became re-united to South America, there is no reason why the herbivores, and with them man, should not inhabit Antarctica to, at least, the same extent as do the Esquimaux the lands around the Arctic Ocean.

If, on the other hand, Antarctica were to increase greatly in size until it assumed proportions like those which, perhaps, belonged to it in Permo-Carboniferous time (when it may have embraced South America, South Africa, and Australia), it is evident, from what is the present effect on climate of the present distribution of land and water respectively at the North and South Poles, that such a huge continent so situated would produce winters of far greater intensity than the present. It has been

argued by me elsewhere that at the maximum glaciation in Permo-Carboniferous time there was a fall of temperature in Australia equal to about 15° to 20° F. This may have been largely brought about by the huge polar continent entirely stopping any large southerly ocean currents, and so removing what is at present one of the most potent means of transfer of heat from the Equator to the Poles.

Passing now to a related matter I wish to strongly urge that more may be done for meteorology in the future than in the past.

In the first place, steps might be taken to establish, at least, a few observing stations in the heart of the Australian meteorological desert, which lies between Nullagine, in Western Australia, and the MacDonnell Ranges.

Next, there is the question of investigating the upper atmosphere by means of kites and small balloons carrying detachable self-registering instruments. By these means the height and movement and temperature of that important isothermal layer of the atmosphere can also be determined.

Next, and this is particularly important, in my opinion, with a view to spreading a knowledge and creating a real and live interest in this beautiful science, a proposal has been made, emanating from the able Director of the Federal Meteorological Bureau, Mr Hunt, that a competent officer be appointed to visit the Australian Universities in turn, opening about one term at each of the six Universities of the Commonwealth, so that all our students for at least one term every two years will have an opportunity of sharing in the delightful and instructive problems presented by our Australian Meteorology.

It may be mentioned in this connexion that a lectureship in meteorology at the Edinburgh and East of Scotland Agricultural College, an event of significance both to meteorology and agriculture, has already been established, and this has been done by a nation not prone to expenditure on that which profiteth not.

This scheme for providing a peripatetic professor of meteorlogy, who could be supplied at a minimum of cost to the Universities, has already been warmly approved by the Universities, and I venture to hope that our Association unanimously wishes to see this professorship an accomplished fact.

Next, there is the important question raised by Mr. Halligan, in his excellent paper dealing with the ocean currents around Australia, as to whether our legislators will some day be impressed

with the necessity for a complete current survey of the coast. This is most important, not only from a meteorological point of view, but also from the views of harbors and navigation generally.[1] "If looked upon in the light of insurance only, the comparatively small expenditure for the complete investigation of the tides and currents on the coast would appear to be amply justified. When we know the forces of nature with which we have to contend, we may with confidence enter upon the largest engineering schemes, and be tolerably certain of success; but it is rash and unscientific to attempt to coerce Nature instead of controlling her, and this we are always liable to do unless the most complete data are at our commands."

Then, too, the question will have to be seriously considered as to whether a permanent wireless meteorological station should not be maintained at Macquarie Island, or some other suitable sub-antarctic island, as already advocated. This would be a stepping stone towards eventually establishing a meteorological station in Antarctica.

Next, there is an allied question which more immediately concerns physical science, but which is also closely connected with meteorology—that of the establishment of a solar physics observatory. This Association has pledged itself to support this proposal—perhaps second to none in importance at the present moment in the field of Australasian scientific research. The scheme has been most ably and zealously advocated by Mr. W. Geoffrey Duffield, and is still being warmly supported by him, and at present an active campaign in its interests is being conducted here in Australia and New Zealand most energetically and unselfishly by the daughter of a very distinguished British astronomer, Miss Mary Proctor. It is of the greatest importance to science that the sun be kept under observation for the whole 24 hours of each day, but in the absence of such an observatory in Australia there is a big blank in the daily observations represented by the distance between India and California, no less than 150° of longitude. Australia is in an ideal position, and possesses an ideal climate for such an observatory.

The total prime cost of such an observatory is estimated at £10,000.

The cost of conducting the observatory is estimated at about £1,500 per annum for the earliest years, with probably an expanding outlay as the work develops.

The highest authorities in the Old Country, such as Sir Joseph Larmor and the late Sir George Darwin, have lent their support to the project no less warmly than do Australasian scientists. The Federal Government of the first Fisher Ministry made, in 1909, this generous offer, which is still open:—"He (the Minister for Home Affairs) realized the importance of the plea for an Australian observatory, and that the financial aid required was probably disproportionate to the value of the scientific records sought to be secured. He thought that Parliament would not be less public spirited than private citizens, and would probably give £1 for £1 to the erection and equipment fund, and might maintain the observatory after its establishment."

This magnanimous offer of the Federal Government, if approved by Parliament, would leave only £5,000 to be raised by private subscription. In 1911, no less than £4,017 of the required £5,000 had been subscribed in money or in kind. The handsome bequest of a fine reflecting telescope valued at £2,000 was made by a single patriotic citizen of Ballarat, Mr. James Oddie.

The Government Astronomer of Melbourne, Mr. P. Baracchi, than whom no one's judgment should carry more weight in such a matter, has selected what he considers to be an eminently suitable site, with excellent climatic conditions, at Yass-Canberra. You will all be pleased to hear that there is every prospect of the Federal Government very soon making this solar physics observatory an accomplished fact. Accurate scientific work, such as would be accomplished at such a solar physics observatory, would not only be of extreme value to science, but would certainly actually pay in the long run, as does all honest scientific research.

In regard to economic results from expenditure on science, as this address has related specially to meteorology, my remarks will refer to it only, though what is true of meteorology is true also of almost all the sciences.

The cost of the maintenance of the United States Weather Bureau now amounts to over £300,000 a year, and the most conservative estimate places the saving to the country brought about by timely forecasts at many times the cost of maintaining the bureau, probably at least £1,000,000, to say nothing of the still more important matter—the saving of so many human lives through warnings to shipping. Our own Commonwealth Meteorological Bureau, with its branches in the various States, costs, at present, £22,000 annually, a small sum when we consider what vast interests are at stake dependent on weather. If we take the case of shipping and agriculture alone, by no means the only interests,

the total number of ships which visited our ports in 1911 was 7,781. Then, in agriculture, Professor Watt estimates that in New South Wales alone, whereas the present value of the wheat yield is about £6,000,000 a year, the existing area under cultivation is capable of having its yield increased by 50 per cent. by more scientific farming, and the whole area may be increased about tenfold, so that New South Wales in the future should produce £90,000,000 where now she is producing £6,000,000. In Victoria, too, the wheat yield can be greatly increased, and the area under cultivation can be, perhaps, doubled. In South Australia, too, the yield could be very much increased, and the yield in Western Australia enormously increased; and all this wheat-growing industry is, of course, specially dependent on weather and weather forecasts.

It is surely up to us from every point of view to strenuously support and continually enlarge the scope of the work of our Meteorological Bureau. It is a service of which Australia has every reason to be justly proud, for, at present, no less than 9 per cent. of the forecasts come true, but though "much is taken, much abides." It was said of old, "Let the consuls look to it that the Republic take no harm," and it is to us, who should be the leaders of scientific thought, that the people of Australasia has a right to look to see to it that no harm comes to the State through neglect of even the least of the sciences in the broadest sense of the word science. We have only to make known our wants, and to reasonably support their claims, and experience has shown us that our Government and private citizens at once rally to our support. But while arguments have just been quoted for subsidizing science because science pays, the fact cannot to too strongly emphasized that it is obviously not desire for pay, beyond the irreducible minimum for satisfying simple needs, that sends the scientific worker up the steep and narrow way of research. It is the love of his work for its own sake and the glamour of the unknown that constrain him. One may never overtake the vision, but is not the glory of pursuing worth all the fardels of this mortal life! Lessing said that if God came to him with the absolute truth in one hand and the pursuit of truth in the other, and bade him choose which he would have, he would choose the pursuit. Surely no true lover of knowledge should choose otherwise to-day!

But are we soldiers of the army of science under the Southern Cross really living up to our highest duties and ideals? Are not we who dwell in ease and peace in a large land, where the scientific harvest is plenteous and the labourers are few, in danger of slackness in the doing of our daily work? We cannot justly blame

for this our climate, which on the whole is one of the best for the white races. Neither can we reasonably urge lack of the stimulus which comes from competition, for if we had the least faith in the reality of our duty to work each day with our might, we should neither slacken nor procrastinate, nor leave ourselves leisure at times for unnecessary, if not ungenerous, criticisms of the work of our fellow craftsmen. But to err is human; and there can be no doubt that partly through want of competition, partly through want of rubbing shoulders with our fellow workers in the Old World, partly through yielding, like the lotus-eaters, to that primitive *dolce far niente* instinct, we do err and fall far short of our duty. This is another instance why we so particularly look forward to the coming of our colleagues of the British Association and their distinguished visitors from other countries, viz., that we may be strengthened and confirmed in our work by means of that inspiration which comes alone from personal contact with master minds.

In the meantime, while as yet our country is untouched by war, war which we hope may never come, though come it surely will, unless we watch continually as a strong man armed, let us work together body and soul to make her as glorious in the arts of peace as she is dear to our hearts, just because it is our bounden duty so to do, and to the end that we may, under Providence, hand down to our children this noble heritage of Australasia as strong and free and full of honour as it was when we received it from our stalwart fathers.

By Authority: Albert J. Mullett, Government Printer, Melbourne.

# SOME CRYSTAL MEASUREMENTS OF CHILLAGITE.

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[With Plates XV, XVI.]

[*Read before the Royal Society of N. S. Wales, December 4, 1912.*]

THE crystals measured and discussed in this paper were kindly supplied to us by Mr. A. J. Ullmann of Chillagoe. In December of last year Mr. Ullmann wrote to Professor David, reporting to him the discovery of what he thought was a new mineral, and forwarding a sample of the same. The new substance was stated by Mr. Ullmann to contain lead, molybdenum and tungsten. It is thus related to both stolzite and wulfenite. As no such mineral combination had hitherto been recorded, the name Chillagite was suggested by Professor David.

The Queensland Department of Mines also obtained samples of the material from the same mine, and an analysis was prepared which was published in February of of the present year. This analysis corresponds closely to the formula $PbO\ MoO_3\ PbO\ WO_3$. Shortly after this Mr. Ullmann submitted a note to this Society giving an account of the occurrence of the mineral and also the results of a qualitative analysis. He also stated that the composition was $PbO\ MoO_3\ PbO\ WO_3$ and gave the theoretical proportions of $PbO$, $MoO_3$ and $WO_3$ for this formula.

In June last, the Queensland Department of Mines forwarded Professor David a copy of a report embodying still later analyses. That portion of the report giving the analyses reads as follows:—

"The report on the previous sample was made on a limited supply of crystals, but the present sample was sufficiently large to allow a more general examination to be made. The present sample differed from the previous one in containing a considerable

proportion of flat orange-yellow transparent crystalline plates, some of these, while quite transparent in the centre, were lemon coloured and translucent on the edges.

"The greater part of the sample was made up of flat crystalline plates, the colour varying from orange-yellow to lemon-yellow, the lemon-yellow parts being only translucent, but the orange coloured parts more or less transparent. Some crystals were dark and opaque in parts, and this was found to be due to an inclusion of carbonate of lead.

"There were just a few other crystals of even lemon yellow colour and of different crystalline habit, the specimens showing an uneven crystalline surface, quite distinct from the flat smooth crystals mentioned above. It was these crystals which were found in the previous sample.

"Two lots of crystals were selected for analysis, the first lot being more or less orange coloured, and the second lot all lemon coloured crystals. The analysis gave 16·8 per cent and 22 7 per cent, of tungstic acid respectively, the lot with the more lemon colour thus showed the more tungstic acid.

"An analysis was then made on a carefully selected lot of the clear transparent orange coloured flat plates. These had a hardness 3 to $3\frac{1}{2}$, and specific gravity 7 05. The analysis showed

| | | |
|---|---|---|
| Tungstic acid ($WO_3$) . | ... | trace |
| Molybdic acid ($MoO_3$) | ... | 39 5 % |
| Lead oxide (PbO) ... | ... | 59·8 % |

proving these crystals to be molybdate of lead. The analysis corresponds approximately to the formula $PbMoO_4$.

"Two lots of the lemon coloured crystals with uneven crystalline surface were then picked. These had a hardness 3 to $3\frac{1}{2}$ and specific gravity 7·30. The analysis showed

| | | (*a*) | (*b*) |
|---|---|---|---|
| Tungstic acid ($WO_3$) | ... | 23·5 % | 21·1 % |
| Molybdic acid ($MoO_3$) | ... | (lost) | 22·0 |
| Lead oxide (PbO) ... | ... | 54·0 | 54·5 |

"This analysis (*b*) corresponds approximately to the formula 3 $PbWO_4$, 5 $PbMoO_4$."

From this report it appears that three types of crystals were present.

(1) Transparent orange coloured plates.

(2) Partly transparent orange coloured and partly translucent lemon yellow plates.

(3) Translucent lemon yellow plates.

The first were shown to be definitely wulfenite. In the third the percentage of tungstic acid is fairly constant, varying from 21.1 to 23.5 per cent. The lead oxide was also constant where determined. The second group of crystals were intermediate in both physical properties and chemical composition to the first and third groups.

The crystals supplied to us by Mr. Ullmann possessed the physical characters of the third type being translucent lemon yellow crystals.

They were set in a gossan matrix commonly having two edges embedded and the other two free. Where the crystals were grouped, they either formed an irregular cell structure or were arranged with an approximate parallelism of the basal planes. In two of the crystals measured three edges were present, but in the remaining five only two edges could be obtained. As the crystals actually measured were small, varying from 1.5 to 3 mm. in diameter, they could not be analysed.

They were flat thin square crystals, the edges being up to 1 cm. in length and about 2 mm. in thickness. The basal planes were large and the pyramid faces of the first order well developed. These appeared to make but relatively small angles (less than 30°) with basal planes. The crystals were extremely brittle and fragile, and only fragments could be obtained for measurement.

The following tables give the measurements recorded for the crystals. These were read on a two circle goniometer. The explanation of the tables is as follows:—

The letters indicate the names proposed for the forms. These are the same as the letters given to similar faces on stolzite and wulfenite where these corresponding forms are known.

The indices are given in Miller's notation. The measured angles for $\phi$ have been placed in two columns which are so arranged that the first order pyramids in either column are in the same zone. The signs + and − prefixed to the $\phi$ reading indicate faces developed on the same and opposite sides of the crystal respectively, as the standard basal plane. Faces underlined in the Tables VI and VII indicate faces in the same zone as but along the opposite edge to the other faces in the same column.

Faces marked with an asterisk are referred to the forms represented by the letters by which they are distinguished, but were not considered to be sufficiently well developed to be included in deducing the mean values represented in Table VIII. The columns marked $E\phi$ and $E\rho$ show the difference in minutes from the mean values of the goniometer measurements. These have been incorporated as a measure of the degree of perfection of the crystal faces. The columns $\delta\phi$ and $\delta\rho$ express the differences of the measured $\phi$ and $\rho$ from the theoretical value calculated from the corresponding indices.

On all the crystals measured two basal planes were present, one of which showed a relatively good signal and the other a very poor one.

The latter was in some cases only represented by an indistinct blur of light. The basal plane with the better signal was in each case selected as the standard of reference for the other faces.

*Crystal No. 1.*—The forms developed are *c*, *f* and *e*. Of these the dominant ones are c and *f*. The faces approximating to the form *y* were too small to be seen, but their reflections show that they were symmetrically developed.

TABLE I.

| Face. | Miller Indices. | Measured $\phi$. | E$\phi$. | Measured $\rho$. | E$\rho$. | Calculated $\phi$ | Calculated $\rho$. | $\rho\phi$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ° ′ | ′ | ° ′ | ′ | | ° | ° ′ | |
| c | 001 | - | 1 | 0 | 2 | - | 0 | - | 0 |
| c′ | 001 | - | 2 | 17 | 2 | - | 0 | - | 17 |
| e | 011 | +5 | ½ | 57 16 | ¼ | 0 | 56 49 | 5 | 27 |
| y | 119 | - 45 38 | 3 | 13 49 | 1 | 45° | 13 30 | 38 | 19 |
| *y | ,, | - 47 5 | 3 | 14 11 | 4 | ,, | ,, | 2 5 | 41 |
| *y | ,, | +46 13 | 3 | 14 21 | 4 | ,, | ,, | 1 | 51 |
| *y | ,, | - 43 10 | 1 | 14 7 | 4 | ,, | ,, | 1 50 | 37 |
| f | 115 | +44 58 | - | 23 17 | ½ | ,, | 23 23 | 2 | 5 |
| f | ,, | - 45 2 | ½ | 23 20 | - | ,, | ,, | 2 | 3 |
| f | ,, | +45 9 | ½ | 23 23 | ½ | ,, | ,, | 9 | 0 |
| f | ,, | - 44 49 | ½ | 23 23 | ¼ | .. | ,, | 11 | 0 |

*Crystal No. 2.*—The chief forms developed are c, $\theta$, $x$ and $f$. Of these c and $f$ are the dominant ones, the latter being symmetrically developed. In the case of the forms $\theta$ and $x$ only one face of each was found. The form $y$ is represented by three faces, but only one of these is reasonably well developed. The faces represented by the forms $\theta$, $X$ and $x$ were not observed on any other crystal measured. The chief forms are represented in figs. 1 and 2, Plate XVI.

TABLE II.

| Face. | Miller Indices. | Measured $\phi$. | E$\phi$. | Measured $\rho$. | E$\rho$. | Calculated $\phi$ | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ ° ′ | ′ | ° ′ | ′ | | ° ′ | ° ′ | ° ′ |
| c | 001 | - | ½ | 0 | ½ | - | 0 | - | 0 |
| c′ | 001 | - | 4 | 4 | 1 | - | 0 | - | 4 |
| $\theta$ | 0 32 | 44 | 1 | 65 3 | 5 | 0 | 66 27 | 44 | 21 |
| X | 0 94 | 10 | 1 | 73 46 | 2 | ,, | 73 48 | 10 | 2 |
| *y | 1 19 | +43 8 | 1 | 12 58 | ½ | 45° | 13 30 | 1 52 | 37 |
| y | ,, | - 44 38 | - | 13 26 | - | ,, | ,, | 22 | 4 |
| *y | ,, | +46 35 | - | 14 38 | - | ,, | ,, | 1 35 | 1 8 |
| *g | 1 16 | +43 12 | 4 | 20 38 | 8 | ,, | 19 49 | 1 48 | 49 |
| *g | ,, | - 43 7 | - | 21 26 | - | ,, | ,, | 1 53 | 1 37 |
| f | 1 15 | - 44 30 | - | 23 16 | - | ,, | 23 23 | 30 | 7 |
| ,, | ,, | +45 13 | ½ | 23 34 | 2 | ,, | ,, | 13 | 11 |
| ,, | ,, | +45 17 | - | 23 42 | 1 | ,, | ,, | 17 | 19 |
| f | 1 15 | - 45 51 | - | 23 45 | - | ,, | ,, | 51 | 22 |
| *d | 1 14 | - 41 48 | - | 28 8 | - | ,, | 28 23 | 3 12 | 22 |
| * ,, | ,, | +45 20 | ½ | 28 45 | 2 | ,, | ,, | 20 | 1 3 |
| *p | 1 11 | - 46 | 1 | 57 19 | ½ | ,, | 56 49 | 1 | 30 |
| ,, | ,, | +45 50 | ½ | 57 32 | 3 | ,, | ,, | 50 | 43 |
| *x | 3 43 | +36 2 | - | 67 19 | 2 | 36°52′ | 68 22 | 50 | 1 3 |
| * ,, | ,, | +36 1 | ½ | 72 43 | 2 | ,, | ,, | 51 | 4 21 |

*Crystal No. 3.*—Few faces were present on this crystal. Only one representative face of each of the forms c, *k*, *G*, *F* and *f* was observed.

TABLE III.

| Face. | Miller Indices. | Measured $\phi$. | | E $\phi$ | Measured $\rho$. | E$\rho$. | Calculated. $\phi$ | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | ′ | ° ′ | ′ | | ° ′ | ° ′ | ′ |
| c | 001 | – | | 8 | 0 | 1 | – | 0 | – | 0 |
| c′ | 001 | – | | ½ | 14 | 1 | – | 0 | – | 14 |
| k | 1 17 | +44 40 | | – | 16 42 | – | 45° | 17 10 | 20 | 28 |
| *,, | 1 17 | -43 27 | | – | 18 1 | – | ,, | ,, | 1 33 | 51 |
| *g | 1 16 | -43 47 | | – | 18 58 | – | ,, | 19 49 | 1 13 | 51 |
| ,, | 1 16 | +44 4 | | – | 18 59 | – | ,, | ,, | 56 | 50 |
| G | 2 2 11 | -44 43 | | – | 21 26 | – | ,, | 21 28 | 17 | 2 |
| F | 3 3 16 | | -44 39 | – | 22 15 | – | ,, | 22 5 | 21 | 10 |
| f | 1 15 | | +44 40 | 1 | 23 47 | ½ | ,, | 23 23 | 20 | 24 |
| *w | 22 5 | -43 45 | | 1 | 40 52 | 1 | ,, | 40 51 | 1 15 | 1 |

*Crystal No. 4.*—This was the only crystal measured on which the form *f* was not present. The dominant faces are c and *l*.

TABLE IV.

| Face. | Miller Indices. | Measured $\phi$. | | E $\phi$. | Measured $\rho$. | E$\rho$. | Calculated $\phi$ | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | ′ | ° ′ | ′ | | ° ′ | ° ′ | ° ′ |
| c | 001 | – | | ½ | 0 | ½ | – | 0 | – | 0 |
| c′ | 001 | – | | ½ | 11 | – | – | 0 | – | 11 |
| *r | 013 | 1 4 | | – | 28 17 | ½ | 0 | 27 1 | 1 4 | 1 16 |
| S | 1 1 10 | | +45 50 | – | 11 43 | – | 45° | 12 12 | 50 | 29 |
| l | 118 | -44 28 | | – | 14 25 | – | ,, | 15 7 | 32 | 42 |
| l | ,, | | -44 56 | – | 14 54 | 1 | ,, | ,, | 4 | 13 |
| l | ,, | | -44 56 | – | 15 39 | 1 | , | ,, | 4 | 32 |
| l | ,, | | -44 56 | – | 16 2 | 1 | ,, | ,, | 4 | 55 |
| d | 114 | -44 1 | | – | 28 30 | – | ,, | 28 23 | 59 | 7 |
| ,, | ,, | | +45 | ½ | 28 41 | – | ,, | ,, | 0 | 18 |
| D | 6 6 23 | | -45 18 | – | 29 10 | ½ | ,, | 29 26 | 18 | 16 |

*Crystal No. 5.*—The chief forms are c, *f* and *l*. The two former are developed symmetrically and determine the shape of the crystal. Ditetragonal pyramids are represented by *z* and $\pi$.

TABLE V.

| Face. | Miller Indices. | Measured $\phi$. | | E $\phi$ | Measured $\rho$. | E $\rho$. | Calculated $\phi$ | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | ′ | ° ′ | ′ | | ° ′ | ′ | ° ′ |
| c | 001 | ... | | 1 | 0 | ½ | – | 0 | – | 6 |
| c′ | 001 | ... | | 5 | 6 | ½ | – | 0 | – | 0 |
| y | 1 19 | | – 45 | 4 | 13 1 | ½ | 45° | 13 30 | 0 | 29 |
| ,, | ,, | | – 45 | 2 | 13 58 | ½ | ,, | ,, | 0 | 28 |
| z | 2 2 17 | +44 56 | | ½ | 14 26 | 1 | ,, | 14 16 | 4 | 10 |
| l | 1 18 | | +45 4 | 3 | 14 50 | 1 | ,, | 15 7 | 4 | 17 |
| l | ,, | | – 45 | ½ | 14 51 | ½ | ,, | ,, | 0 | 16 |
| l | ,, | +45 | | ½ | 15 39 | – | ,, | ,, | 0 | 32 |
| l | ,, | | +45 4 | – | 15 43 | 1 | ,, | ,, | 4 | 36 |
| g | 1 16 | | – 44 21 | 1 | 19 32 | ½ | ,, | 19 49 | 39 | 17 |
| *f | 1 15 | – 45 52 | | ½ | 22 11 | 1 | ,, | 23 23 | 52 | 1 12 |
| f | 1 15 | +44 45 | | 1 | 23 7 | 21 | ,, | ,, | 15 | 16 |
| f | ,, | | – 45 | ½ | 23 13 | – | ,, | ,, | 0 | 10 |
| f | ,, | +45 15 | | ½ | 23 23 | 2 | ,, | ,, | 15 | 0 |
| f | ,, | | +44 56 | 21 | ,, | 1 | ,, | ,, | 4 | 0 |
| f | ,, | – 45 20 | | 1 | 24 20 | 5 | ,, | ,, | 20 | 57 |
| D | 6 6 23 | – 45 4 | | 1 | 29 8 | 3 | ,, | 29 26 | 4 | 18 |
| D | ,, | +44 46 | | 2 | 29 28 | ½ | ,, | ,, | 14 | 2 |
| b | 1 13 | +45 9 | | ½ | 36 5 | 1 | ,, | 35 47 | 9 | 18 |
| b | ,, | – 44 53 | | ½ | 36 12 | 5 | ,, | ,, | 7 | 25 |
| *z | 2 77 | – 16 17 | | 0 | 56 26 | ½ | 15 57 | 57 50 | 20 | 1 24 |
| $\pi$ | 1 33 | +18 57 | | 20 | 57 42 | ½ | 18 26 | 58 11 | 31 | 29 |

*Crystal No. 6.*—Three sides of this crystal were available for measurement. The dominant forms are *c*, *f* and *l*. The second order pyramids are represented by *e* which is not however well developed. The forms *d* and *p* are also worthy of mention as they represent faces with simple indices.

TABLE VI.

| Face. | Miller Indices. | Measured $\phi$. | | E $\phi$. | Measured $\rho$. | E $\rho$. | Calculated $\phi$. | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | ′ | ° ′ | ′ | | ° ′ | ° ′ | ° ′ |
| c | 001 | | – | $\frac{1}{2}$ | 0 | - | – | 0 | – | 0 |
| c′ | 001 | | - | 10 | 21 | 3 | – | 0 | – | 21 |
| *e | 0 11 | | 2 36 | – | 58 42 | - | 45° | 56 49 | 2 36 | 1 53 |
| *Y | 1 1 18 | +47 57 | | 2 | 6 47 | $\frac{1}{2}$ | „ | 6 51 | 2 57 | 4 |
| *Y | „ | | +42 43 | 2 | 7 7 | $\frac{1}{2}$ | „ | „ | 2 17 | 16 |
| *y | 1 19 | +43 37 | | $\frac{1}{2}$ | 11 46 | $\frac{1}{2}$ | „ | 13 30 | 1 23 | 1 44 |
| *„ | „ | | +47 9 | 1 | 12 12 | $\frac{1}{2}$ | „ | „ | 2 9 | 1 18 |
| *„ | „ | | +46 50 | – | 13 5 | $\frac{1}{2}$ | „ | „ | 1 50 | 25 |
| „ | „ | −44 30 | | 2 | 13 30 | 33 | „ | „ | 30 | 0 |
| *l | 1 18 | +46 36 | | 4 | 14 24 | 5 | „ | 15 7 | 1 36 | 43 |
| *„ | „ | | +46 37 | 5 | 14 51 | $\frac{1}{2}$ | „ | „ | 1 37 | 16 |
| *„ | „ | | +40 15 | $\frac{1}{2}$ | 15 30 | 2 | „ | „ | 4 45 | 23 |
| „ | „ | −44 27 | | 2 | 15 40 | 7 | „ | „ | 33 | 33 |
| „ | „ | | −45 57 | 3 | 16 15 | – | „ | „ | 57 | 1 8 |
| *„ | „ | | +46 18 | $\frac{1}{2}$ | 16 22 | $\frac{1}{2}$ | „ | „ | 1 18 | 1 15 |
| *k | 1 17 | | −43 45 | 2 | 18 27 | 3 | „ | 17 10 | 1 15 | 1 17 |
| *g | 1 16 | | −43 51 | 1 | 20 6 | 4 | „ | 19 49 | 1 9 | 17 |
| G | 2 2 11 | +45 2 | | 1 | 21 5 | 7 | „ | 21 28 | 2 | 23 |
| F | 3 3 16 | −45 10 | | 1 | 22 5 | 2 | „ | 22 5 | 10 | 0 |
| „ | „ | | −44 50 | 1 | 22 29 | 5 | „ | „ | 10 | 24 |
| „ | „ | | +45 5 | $\frac{1}{2}$ | 22 37 | 3 | „ | „ | 5 | 32 |
| f | 1 15 | +45 | | 1 | 23 13 | 3 | „ | 23 23 | 0 | 10 |
| f | „ | | −45 52 | 2 | 23 35 | 1 | „ | „ | 52 | 12 |
| *f | 1 15 | | −45 53 | – | 24 30 | – | „ | „ | 53 | 1 7 |
| *d | 1 14 | | +46 6 | 20 | 27 44 | 10 | „ | 28 23 | 1 6 | 39 |
| „ | „ | | −45 2 | 13 | 27 56 | 4 | „ | „ | 2 | 27 |
| *„ | „ | | +43 47 | 19 | 29 21 | 7 | „ | „ | 1 13 | 58 |
| *„ | „ | −40 10 | | 1 | 30 44 | $\frac{1}{2}$ | „ | „ | 4 50 | 2 21 |
| p | 1 11 | | +44 49 | $\frac{1}{2}$ | 64 40 | – | „ | 65 11 | 11 | 31 |
| *„ | „ | | +45 33 | 2 | 66 46 | - | „ | „ | 53 | 1 35 |

*Crystal No. 7.*—This crystal also possessed three sides which could be measured. The forms c, *f* and *d* are prominently developed. All the other forms present possess at least one good representative face.

TABLE VII.

| Face. | Miller Indices. | Measured $\phi$. | | $E\phi$. | Measured $\rho$. | $E\rho$ | Calculated $\phi$. | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | ′ | ° ′ | ′ | | ° ′ | ° ′ | ′ |
| c | 001 | — | | 1 | 0 | 3 | — | 0 | — | 0 |
| c′ | 001 | — | | 3 | 4 | ½ | — | 0 | — | 4 |
| S | 1 1 10 | +44 55 | | - | 12 36 | - | 45° | 12 12 | 5 | 24 |
| *l | 1 18 | | +43 39 | - | 15 10 | - | ,, | 15 7 | 1 21 | 3 |
| l | ,, | +45 42 | | - | 15 31 | - | ,, | 15 7 | 42 | 24 |
| k | 1 17 | | -44 57 | - | 17 16 | ¼ | ,, | 17 10 | 3 | 6 |
| g | 1 16 | | -44 51 | - | 19 21 | 2 | ,, | 19 49 | 9 | 28 |
| G | 2 2 11 | | +45 | ½ | 21 26 | ¼ | ,, | 21 28 | 0 | 2 |
| F | 3 3 16 | | -45 | 2 | 22 4 | 2 | ,, | 22 5 | 0 | 1 |
| f | 1 15 | -44 35 | | - | 23 25 | - | ,, | 23 23 | 25 | 2 |
| f | ,, | | +45 10 | 1 | 23 29 | - | ,, | ,, | 10 | 6 |
| f | ,, | -44 28 | | - | 23 57 | - | ,, | ,, | 32 | 34 |
| d | 1 14 | -44 29 | | - | 27 56 | - | ,, | 28 23 | 31 | 33 |
| d | ,, | +44 35 | | - | 28 12 | - | ,, | ,, | 25 | 11 |
| d | ,, | | +45 14 | 2 | 28 32 | - | ,, | ,, | 14 | 9 |
| d | ,, | | +44 54 | 15 | 28 44 | - | ,, | ,, | 6 | 21 |

The following table gives the mean values of $\phi$ and $\rho$ and their differences from the calculated values. It also shows the number of faces considered in deducing these mean values and the variations in their measurements.

TABLE VIII.

| Form. | Miller Indices. | No. of Faces. | Range of $\phi$. | Range of $\rho$. | Mean $\phi$ | Mean $\rho$ | Calculated $\phi$. | Calculated $\rho$. | $\delta\phi$. | $\delta\rho$. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ° ′ ° ′ | ° ′ ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ | ° ′ |
| $\tau$ | 013 | 1 | ... | ... | 1 4 | 28 17 | 0 | 27 1 | 1 4 | 1 16 |
| e | 011 | 1 | ... | ... | 5 | 57 16 | 0 | 56 49 | 5 | 27 |
| $\theta$ | 032 | 1 | ... | ... | 44 | 65 8 | 0 | 66 27 | 44 | 1 24 |
| X | 094 | 1 | ... | ... | 10 | 73 46 | 0 | 73 48 | 10 | 2 |
| Y | 11 18 | 1 | ... | ... | 47 57 | 6 47 | 45 | 6 51 | 2 57 | 4 |
| S | 11 10 | 2 | 44 55 – 45 50 | 12 36 – 12 41 | 45 5 | 12 38 | 45 | 12 12 | 5 | 26 |
| y | 119 | 6 | 44 30 – 46 0 | 13 21 – 13 51 | 44 58 | 13 43 | 45 | 13 30 | 2 | 13 |
| Z | 22 17 | 1 | ... | ... | 44 56 | 14 26 | 45 | 14 16 | 4 | 10 |
| l | 118 | 10 | 44 27 – 45 42 | 14 25 – 16 2 | 44 57 | 15 13 | 45 | 15 7 | 3 | 6 |
| k | 11 7 | 2 | 44 40 – 44 57 | 16 42 – 17 16 | 44 50 | 17 2 | | 17 10 | 10 | 8 |
| g | 116 | 3 | 44 4 – 44 51 | 18 59 – 19 32 | 44 40 | 19 31 | 45 | 19 49 | 20 | 18 |
| G | 22 11 | 3 | 44 43 – 45 2 | 21 5 – 21 26 | 44 56 | 21 21 | 45 | 21 28 | 4 | 7 |
| F | 33 16 | 5 | 44 39 – 45 10 | 22 4 – 22 37 | 44 58 | 22 18 | 45 | 22 5 | 2 | 13 |
| f | 115 | 19 | 44 28 – 45 51 | 23 7 – 24 20 | 45 | 23 26 | 45 | 23 23 | 0 | 3 |
| d | 114 | 7 | 44 1 – 45 14 | 28 12 – 28 56 | 45 6 | 28 35 | 45 | 28 23 | 6 | 12 |
| D | 66 23 | 8 | 44 46 – 45 18 | 29 8 – 29 28 | 45 2 | 29 17 | 45 | 29 26 | 2 | 9 |
| b | 113 | 2 | 44 53 – 45 9 | 36 5 – 36 12 | 45 1 | 36 8 | 45 | 35 47 | 1 | 21 |
| w | 225 | 1 | ... | ... | 43 45 | 40 52 | 45 | 40 51 | 1 15 | 1 |
| p | 111 | 3 | 44 49 – 45 60 | 64 40 – 65 54 | 44 58 | 65 20 | 45 | 65 11 | 2 | 9 |
| z | 277 | 1 | ... | ... | 16 17 | 56 26 | 15 57 | 57 50 | 20 | 1 24 |
| $\pi$ | 133 | 1 | ... | ... | 18 57 | 57 42 | 18 26 | 58 11 | 31 | 29 |
| x | 348 | 1 | ... | ... | 36 2 | 67 19 | 36 52 | 68 22 | 50 | 1 3 |

The stereographic projection (Plate XV) exhibits most of the forms in the above table. Some have been omitted to avoid confusion.

The combinations of the forms present on each crystal are shown in the table below. The asterisk has the same significance as in the previous tables:—

| Crystal | c | $\tau$ | e | $\theta$ | X | Y | S | y | Z | l | k | g | G | F | f | d | D | b | w | z | $\pi$ | p | x |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. 1 | c | – | e | – | – | – | – | y | – | – | – | – | – | – | f | – | – | – | – | – | – | – | – |
| „ 2 | c | – | – | $\theta$* | X | – | – | y | – | | – | g* | – | – | f | d* | – | – | – | – | – | p* | x* |
| „ 3 | c | – | – | – | – | – | – | – | – | – | k | g* | G | F | f | – | – | – | w* | – | – | – | – |
| „ 4 | c | $\tau$* | – | – | – | – | S* | – | – | l | – | – | – | – | – | d | D | – | – | – | – | – | – |
| „ 5 | c | – | – | – | – | – | – | y | Z | l | – | g | – | – | f | – | D | b | – | z* | $\pi$ | – | – |
| „ 6 | c | – | e* | – | – | Y* | – | y | – | l | k* | g* | G | F | f | d | – | – | – | – | – | p | – |
| „ 7 | c | – | – | – | – | – | S | – | – | l* | k | g | G | F | f | d | – | – | – | – | – | – | – |

The most prominent faces developed as shown by the above tables are:—*c*, *y*, *l*, *k*, *g*, *G*, *F*, *f* and *d*, of these the faces *c*, *y*, *l* and *p* are the most common.

*Form C.*—In all the crystals two basal planes were present, one of which showed a fairly good signal and the other a poor one. The angles between the basal planes as recorded vary from 4′ to 21′.

*Forms y and l.*—These are closely related as they represent the 119 and 118 faces respectively. The former has been found prominently developed on stolzite.[1]

*Form f.*—The faces belonging to the form *f* (115) are developed on all the crystals measured, with the exception of crystal 4. This crystal appeared on inspection to be similar to the others measured. Very possibly this is due to the form *d* (114) being more prominently developed than in the case of the other crystals. The readings for the faces of the form *f* were so constant that this face was taken as the standard. Eighteen faces of this form were developed. The $\rho$'s of four of them were exactly 23° 23′; the mean reading of the 19 faces developed gave the value as 23° 26′.

Knowing that the crystals measured were related to wulfenite and stolzite, the measurement of these minerals as recorded in Goldschmidt were referred to, in order to connect them with the crystal measurements if possible. The standard value 23° 23′ was nearest the value 26° 22′ which was the $\rho$ for the 229 faces on wulfenite. Assuming the indices of the standard face to be 115, the $\rho$ for the 011 face was brought into the closest agreement with that for the 011 face of both wulfenite and stolzite.

By means of this standard face the value of the "c" axis was determined as :— 1. 5291

That of wulfenite is 1. 5774 }[2]

That of stolzite is 1. 5606 }

[1] E. Artini, Uber den Stolzit von Bena, Padru (Ozieri) Zeit. f. Kryst. Vol. XLIII., pp. 422-3, 1907.

[2] Goldschmidt, Krystallographische Winkeltabellen.

The examination of the crystals from the measurements in the tables show that they belong to the tetragonal system. The scanty development of ditetragonal pyramids and the entire absence of any prism faces renders it somewhat doubtful as to which group the crystal belongs. The marked difference in the degree of development of the basal planes suggests that the crystals may be hemimorphic. This unequal development of the basal planes has been recorded both for wulfenite[1] and stolzite.[2] Provisionally, therefore, the crystals have been classed in the pyramidal hemimorphic group.

The following table shows the faces common to the crystals measured, wulfenite and stolzite respectively:—

| | 1. Chillagite. | 2. Wulfenite. | 3. Stolzite. |
|---|---|---|---|
| 013 | $\tau$ | $\tau$ | $\tau$ |
| 011 | e | e | e |
| 032 | $\theta$ | $\theta$ | — |
| *113 | b | b | b |
| 111 | p | p | p |
| 133 | $\pi$ | $\pi$ | $\pi$ |
| *115 | f | — | f |
| *117 | k | — | k |
| *119 | y | — | y |

The forms marked with an asterisk have been recently recorded as new for stolzite.[3] It thus appears that though in their occurrence the crystals are associated with wulfenite, their crystal measurements are more nearly related to stolzite.

The value of c axis is not intermediate to that of stolzite or wulfenite, but is less than that of either of these minerals.

[1] Charles A. Ingersoll, On Hemimorphic Wulfenite Crystals from New Mexico. Am. Jour. Science, 1894.

[2] Dr. C. Hlawatsch, On Stolzite and a new Mineral Raspite from Broken Hill. Rec. Geol. Surv. N.S.W., 1898, Vol. vi, Part 1, pp. 51 – 61.

[3] E. Artini, *loc. cit.*

It is possible that a small percentage of scheelite or fergusonite molecules may be present, and this might account for the low value of c.[4] Moreover the value c for chillagite differs considerably from the range of values recorded for stolzite or wulfenite. The values of c recorded for stolzite are:—

| | | | |
|---|---|---|---|
| (1) | 1.5576 [1] | (6) | 1.5613 [2] |
| (2) | 1.5579 [2] | (7) | 1.5631 [2] |
| (3) | 1.5586 [2] | (8) | 1.5667 [4] |
| (4) | 1.5597 [2] | (9) | 1.5692 [5] |
| (5) | 1.5606 [3] | | |

For wulfenite the only values of c found were:—

1.7771 [4] 1.7774 [6]

There thus appears to be some evidence in favour of the crystals representing a new mineral, but more is needed before this can be definitely established.

Our thanks are due to Dr. C. Anderson of the Australian Museum for advice in connection with part of the work.

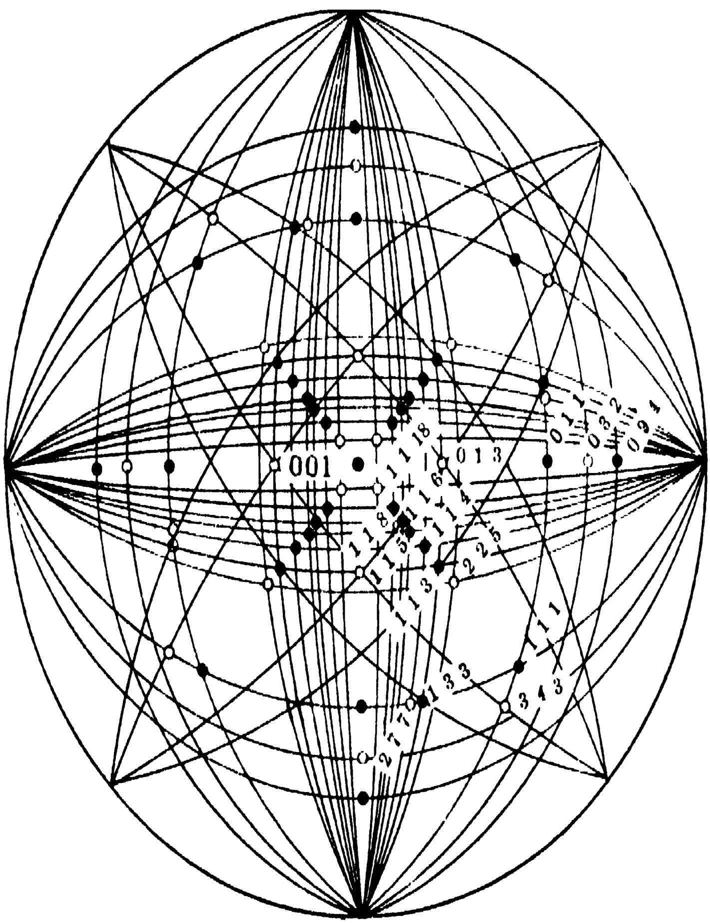
## EXPLANATION OF PLATES.

Plate XV is the Stereographic Projection of most of the forms found. A number of important forms have been omitted to avoid confusion in the figure The forms represented by open circles are not so well developed as those represented by the black dots.

Plate XVI, fig. 1 is an Orthographic Projection of Crystal 2.

Fig. 2 is the corresponding Clinographic Projection of Crystal 2.

[1] Zeit. f. Kryst. Vol. XLIII, 1907. [2] Hlawatsch, *loc. cit.* [3] Hlawatsch, Uber Stolzit and Raspit von Brokenhill, Zeit f. Kryst. Vol. XXIX. [4] Zeit. f. Kryst. Vol, XLV, 1908, p. 93. [5] A. Levy, On a tungstate of lead, Ann. of Phill,, Neue Serie, XII, p. 364. [6] Goldschmidt, *loc. cit.*


001
0 1 3
1 1 1
1 3 3
3 4 3

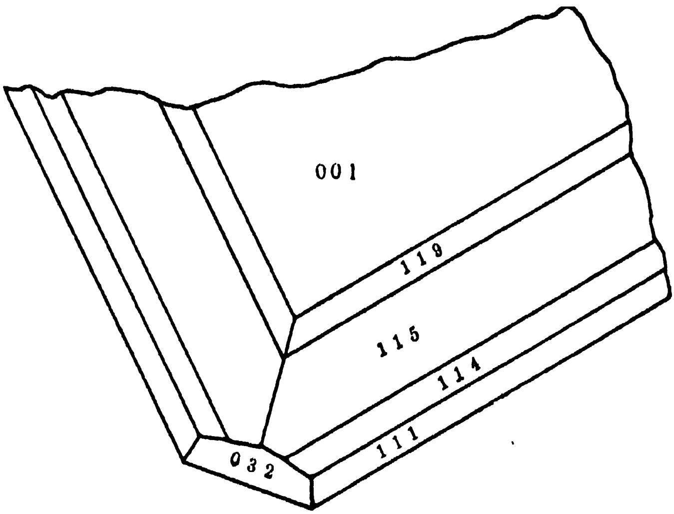



Fig. 1.

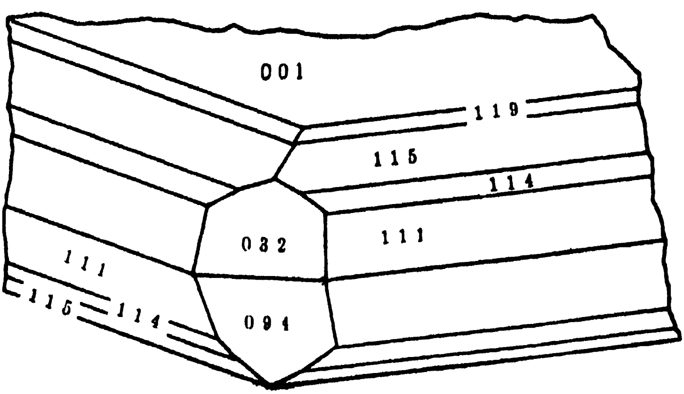



Fig. 2.

# ON ROCK SPECIMENS FROM CENTRAL AND WESTERN AUSTRALIA.

# ON ROCK SPECIMENS FROM CENTRAL AND WESTERN AUSTRALIA.

## COLLECTED BY THE ELDER SCIENTIFIC EXPLORING EXPEDITION OF 1891-2.

By J. ALLAN THOMSON, B.A., D.Sc., F.G.S.

(Communicated by Prof. David, B.A., C.M.G., F.R.S., Hon. D.Sc., Oxon.)

[With Plate XIV.]

[*Read before the Royal Society of N. S. Wales, November 1, 1911.*]

THE rocks described in the present paper were presented to Professor David by Mr. Richard Helms, the naturalist of the Elder Scientific Exploring Expedition of 1891-2. Through the kindness of the former gentleman the writer was permitted to examine the collection and prepare the following notes on the rocks.

The expedition, well equiped by Sir Thomas Elder, crossed from South Australia to the Murchison Goldfield in the years 1891 and 1892.[1] A large number of rock specimens were collected all along the route, and a brief account of these, and of the chief geological features of the country passed over has been given by Mr. Victor Streich.[2] The rocks here described appear to be in some respects supplementary to those listed by Mr. Streich. One of them comes from Fraser's Range, E.N.E. of Norseman, W.A.,

[1] *Cf.* Lindsay, D., Journal of the Elder Scientific Exploring Expedition. 1891-2. With Maps. Adelaide, 1893.

[2] Trans. Roy. Soc., South Austr., Vol. XVI, Part II, 1893, pp. 74 - 110; also Stelzner, A. W., Supplementary Notes on the above named Collection *ibid.*, pp. 110-2. Tate, R., Appendix, List of Rock-specimens collected by Mr. Wells, Second Officer, on a Journey east from Murchison Goldfield, *ibid.*, pp. 113-5. Map of route showing position of camps and geological formations, *ibid.*, facing p. 236.

the other sixteen come from localities between the Barrow Ranges and the Everard Range, *i.e.* between longitudes 127° E. and 132° E., and latitudes 25° S. and 28° S.

Considerable practical interest attaches to the geology of this region. In the first place it lies not far north of the country to be traversed by the proposed Transcontinental Railway from Port Augusta to Kalgoorlie or Esperance; and in the second, it lies to the east of the great belt of gneiss that forms the eastward boundary of the gold-fields of Western Australia, and there is still the possibility that new gold-fields will be found once the gneiss is crossed. The rocks, however, are not of a nature to give us as much information on the solid geology as might have been hoped, since they appear to be in large measure dyke rocks; on the other hand, some of them possess great intrinsic interest.

The gneissose belt referred to has been recently traversed and described by Mr. C. G. Gibson, for the Geological Survey of Western Australia.[1] His map shows a large granitic or gneissic belt lying east of the greenstone belt in which Kanowna, Bulong and Mount Monger lie. The belt trends to the north-east and is succeeded on the east by the Tertiary limestones of the Hampton Tableland. Lindsay's route in this part lay entirely within the gneiss, and this accounts for the paucity of fundamental rocks collected, for the gneiss area is largely covered by sand and spinifex flats. Streich considered this part of the country as "the most westerly part of the Great Australian mesozoic basin." The outcrops which he considered mesozoic, viz., "a system of terraces, having a general N.W. and S.E. trend, their strata dipping at a low angle to the North-

[1] The Geological Features of the Country lying along the Route of the Proposed Transcontinental Railway in Western Australia, Bull. 37, Geol. Surv. W.A., 1909.

East" are probably superficial deposits of desert origin similar to the surface quartzites of the South African arid regions. Dr. J. M. Maclaren has informed me that he has found such terraces northwards from Leonora, and that he considers them of analogous origin to the ferruginous laterites of Western Australia, and proposes to designate them by the name of "siliceous laterites."

The only rock in the collection from the southern end of this gneiss belt is that from Fraser's Range. It is practically identical with a rock collected by Gibson from Simon's Hill, Fraser's Range, and labelled "gneiss" in the Register of the Geological Survey of Western Australia (No. 8696). Besides garnetiferous gneiss, garnetiferous mica schist and pegmatite from Fraser's Range. Streich records a hornblendic schist as forming the main mass of the range, of which rock Stelzner writes:—"671 is according to the microscopic examination of the rock section, an undecomposed diabase, which is distinguished on account of its containing highly pleochroic augite and biotite and apatite as accessory components." This is obviously the rock now to be described.

The hand specimen is a dark, distinctly banded rock, the banding being due to the separation of the felspathic and the femic minerals into poorly defined layers. Microscopic examination shows that the latter minerals consist preponderatingly of hypersthene, with subordinate biotite and rare hornblende. Iron ores and apatite are the only accessories (Fig. 1, Plate XIV). The felspars are sometimes twinned on the albite and pericline laws, but the twinning is fine and not very constant, and is absent in many of the crystals. They all possess refractive indices superior to that of Canada Balsam, so may be all referred to plagioclase. The largest extinctions on symmetrically placed albite lamellae amount to 19°, indicating a species at least as basic as andesine. The felspars never show

crystal outlines, but form a polygonal mosaic of uneven grain. No evidence of cataclastic structure is seen, but strain shadows are not rare. The hypersthene is a little schillerised, strongly pleochroic variety with rose-red to green tones, and is optically negative with a fairly high optic axial angle. It occurs in irregular layers which have a rude parallel arrangement, but within the layer the mineral is not definitely oriented. It has sometimes considerable tendency to idiomorphism, but when surrounded by felspars occurs in more rounded forms. Closely associated with, and often penetrating, the hypersthene is a considerable amount of reddish-yellow to black biotite. In Helm's specimen, but not in Gibson's, there is a little common green hornblende intergrown with the hypersthene. Apatite is fairly abundant in stout prisms with a general elongation in the direction of the banding. Fig. 1, Plate XIV, gives an adequate idea of the relative proportions of the different minerals.

While it is not impossible that the rock belongs to the gneissic series, its structure and mineralogical composition suggest, as more probable, that it is of directly igneous origin, as Stelzner supposed, and is a norite with feeble protoclastic structure and well marked fluxion banding. The presence of hypersthenic dyke rocks at Norseman[1] makes the presence of norite dykes in the Fraser Range quite probable.

The northward extension of this gneiss belt has not yet been delimited by the Western Australian Geological Survey. Apparently the western margin turns north towards Burtville, where the gneiss is found a few miles east of the town.[2] The eastern boundary is unknown in the northern part.

[1] Campbell, W. D., The Geology and Mineral Resources of the Norseman District, Dundas Goldfields, Bull. 21, Geol. Surv. W.A., 1906, p. 24.
[2] Gibson, C. G., The Laverton, Burtville and Erlistown Auriferous Belt, Mount Margaret Goldfield, Bull. 24, Geol. Surv. W.A., 1906, pp. 29, 30.

Two rocks in the Helms' collection are possibly to be referred here. The first is labelled "12 miles N.W. of Camp 23, 17/7/91," *i.e.*, in the northern part of the Blyth Range. It has the appearance and mineralogical composition of a hornblende granite, but some peculiarities in structure, though neither hand specimen or section show any parallel structure. Both orthoclase and quartz are abundant, together comprising the bulk of the rock, and the first peculiarity is the relation of these two minerals. Large pseudoporphyritic plates of orthoclase are found enclosing small rounded grains of quartz in poecilitic fashion (Fig. 2, Plate XIV). Such a structure, if original, as there seems no reason to doubt it is, may be explained by the fact that the magma originally contained quartz in excess of that required for the quartz-felspar eutectic.[1] The structure is, however, further complicated by the presence of a thin zone of quartz-felspar intergrowth between the host and the enclosed mineral. Outside the large plates of orthoclase such intergrowths are very abundant, but are always of fine grain, and have a great tendency to resemble gridirons rather than the script-like forms that have given rise to the term 'graphic.' Their presence between the orthoclase and enclosed quartz suggests that they are not original, but of the nature of 'myrmekite,' a type of structure which in Sweden and Finland is taken to prove great metamorphism and the Archæan age of the granite.[2] Besides orthoclase there is also a smaller amount of microcline and oligoclase, both bounded by similar intergrowths. The oligoclase is sometimes included within the orthoclase. All these minerals occasionally show strain shadows. The

[1] *Cf.*, quartz in oligoclase. Dwerryhouse, A. R., On some Intrusive Rocks in the Neighbourhood of Eskdale (Cumberland), Q.J.G.S., LXV, 1909, pp. 63 and 70.

[2] Holmquist, J. P, Studien uber die Granite von Schweden. Bull. Geol. Inst, Upsala, VII, 1904-5, Nos. 13, 14, p. 116.

dark minerals, iron-ores, hornblende and biotite occur in intricate clusters, along with much apatite and a little zircon. The hornblende is almost opaque from dusty magnetite inclusions, is intimately penetrated by biotite and is embraced by compact iron ores, around which and in the bays of which biotite is freely developed. The rock may therefore be interpreted as a hornblende granite, probably belonging to the gneiss series.

The second rock is labelled "10 miles E. of Camp 33," *i.e.*, from the east of the Barrow Range. Streich states that the Barrow Range consists of eruptive granite, but mentions the occurrence ten miles east of the range of two small "isolated hills of granulite, which is distinctly stratified with a low angle of dip towards south." Stelzner remarks of one of these specimens that "it resembles so closely the granulite of the Saxon granulite-ellipsis that it could have been found there as well." The present specimen is distinctly banded in yellow and dark layers, and presents considerable superficial resemblance to the more yellow varieties of jaspers so abundant in the goldfields of Western Australia. It differs from them, however, in a profusion of small red garnets, which when examined with a lens show no sign of crystal faces. In addition the lens reveals an abundance of an elongated well cleaved colourless mineral with adamantine lustre.

In section the latter mineral shows prismatic forms, with a perfect longitudinal cleavage, has straight extinction, positive elongation, and a birefringence considerably superior to that of quartz (between ·015 and ·020 according to Levy and Lacroix's colour scale). Basal sections are approximately quadrate in shape, and by their study the mineral is shown to be almost uniaxial and optically positive; the opening of the axial brushes is almost imperceptible. An examination of tho crushed mineral in liquids of

known refringence prove the maximum refractive index to be in the neighbourhood of 1·658. This combination of properties precludes identification with any well known uniaxial mineral. To test the possibility of the mineral being phenacite, Mr. G. J. Burrows very kindly undertook a qualitative examination of the rock for beryllium, but with negative result. There is no common biaxial mineral of low axial angle which agrees in all the above characters, and as the amount of material was too small to permit of isolation and chemical analysis, the mineral must be left unidentified for the present.

The other minerals present are quartz and orthoclase in large amount, magnetite in smaller quantity and occasional crystals of zircon. The yellow colour of the rock is due to staining by limonite, the orthoclase in particular being striated by plates of this mineral along the cleavage planes. The quartz and orthoclase form an uneven grained mosaic with a limonitic cement, a structure which in many respects suggests a clastic origin. On the other hand the nearly constant orientation of the unnamed mineral, and an alternation of bands of clear mosaic with other bands containing magnetite and limonite points more strongly to a parallel structure developed in situ (Fig. 3, Plate XIV). It is reasonable to suppose that the rock is a member of the gneissose series.

There is only one rock that resembles the rocks of the auriferous areas of Western Australia, and it is from the Cavanagh Range. The hand specimen is a light green aphanatic rock, which shows when wetted a few veinlets of lighter colour. The section shows that it consists predominatingly of fine grained albite and clinozoisite with smaller amounts of a pale actinolite, chlorite, sphene and accessory apatite. The felspars, in bundles of sub-radiating prisms, form a network within which the other minerals

lie in characteristic forms, clinozoisite and sphene in granules, actinolite and chlorite in more or less elongate prismatic forms. There are in addition a few nests of secondary quartz and epidote, while the veinlets are seen to consist of clinozoisite with a little sphene. The rock is a fine grained amphibolite, rather more felspathic than usual.

Rocks very similar to this are of frequent occurrence in the goldfields of Western Australia, *e.g.*, Kalgoorlie, Norseman, the Murchison Valley, etc. They seem to form the country into which large dykes of coarse grained basic rocks, now also amphibolites, have been intruded, and may therefore be termed the older amphibolites. As a rule these fine grained amphibolites are not conspicuously auriferous, except near the contact of graphite or quartz-porphyry. The specimen, however, is of considerable importance in showing that the rocks of the known auriferous belts are found as far eastwards as the Cavanagh Range.

The remaining rocks are probably intrusive, though the interpetation of some is not without doubt. A rock from Skirmish Hill (22/7/91) is probably to be identified as a much altered quartz porphyry. The hand specimen is grey-black and aphanatic except for red phenocrysts of felspar. In section these phenocrysts are excessively turbid, but may be identified as orthoclase in many cases, although an acid plagioclase also appears to be present. Apatite occurs in large prisms of such size as to deserve the name of phenocryst, and magnetite also occurs in large grains. Much more abundant than the felspar is quartz, in very perfectly elliptical shapes. Sometimes these are occupied by one large plate of quartz, with a marked rim of dusty inclusions at a short distance from the margin, or a marginal fringe of small grains, at other times by a mosaic of grains of smaller size. Though bearing much resemblance

to amygdules, these elliptical plates of quartz may perhaps be more correctly interpreted as corroded phenocrysts round which a secondary deposition of quartz has taken place. The groundmass consists of a fine grained structureless aggregate of quartz, turbid felspar and magnetite with an abundance of chlorite much stained by limonite. The rock is therefore a porphyry, and perhaps a quartz-porphyry. Streich states that Skirmish Hill is composed in the main of a porphyritic syenite.

Another rock, certainly a dyke rock, is labelled Cavanagh Range. It is a dark grey, very finely crystalline rock in hand specimens. In section it is seen to be porphyritic, the phenocrysts being in part small euhedral prisms of red-violet, slightly pleochroic titaniferous augite, and in part much larger pseudomorphs of some earlier mineral. The pseudomorphs now consist mainly of chlorite (pennine) with a less amount of carbonates, sphene and flakes of tremolite. Their forms are distinctly suggestive of olivine, although if they represent this mineral, the alteration is an unusual one. The groundmass of the rock is made up largely of small prisms of brown-green hornblende, often green on the margin. They contain occasional small kernels of augite and are surrounded by short fibrous outgrowths of paler hornblende. Next in importance comes felspar in short multiply twinned lath-shaped or radially built forms. The low birefringence, refractive indices less than that of Canada Balsam, and extinction angles up to 15°, refer the species to albite. Here and there large nests of yellow epidote are found, in whose neighbourhood the hornblende is chloritised and carbonates are abundant. Small iron ores are plentifully scattered throughout the groundmass; their form refers them to the magnetite group, while a partial alteration into sphene shows that they are titaniferous (titanomagnetite).

The rock is certainly an augite-hornblende lamprophyre, probably a camptonite. It is the first rock of this class so far found in Western Australia.[1]

A rock of very peculiar character may be described here, as it has some faint resemblance to the camptonite just described, (Cavanagh Range, 31/7/91). It is probably the rock referred to by Streich as tachylite, of which Stelzner remarks:—"This rock is of such an extremely fine grain that I cannot determine it, even with the aid of the microscope on rock sections." The hand specimen is a dark aphanitic rock with some superficial resemblance to a tachylite, but contains a few clear patches of quartz and small geodes containing pyrites. The section (Fig. 4, Plate XIV) shows a number of small elliptical and larger irregularly shaped areas formed of small rods of almost opaque material grouped together like bundles of faggots; between these bundles and acting as a cement are clearer areas consisting of irregular biotite flakes and an indeterminate green mineral in a fine grained quartz base. The green mineral possesses a higher birefringence and lower refringence than the biotite, but a similar absorption and a pleochroism from opaque to dark green or yellow. It appears to be uniaxial or feebly biaxial, is optically negative with positive elongation. The dispersion is very strong, comparable to that of chloritoid, from which, however, it differs in its direction of maximum absorption and its lack of polysynthetic twinning. Most often it occurs in shapeless plates, but occasionally gives lozenge-shaped sections. These differ from hornblende only in the absence of cleavage planes. The mineral thus appears to be intermediate between biotite and chloritoid in its characters, and may possibly be pseudomorphous after hornblende.

[1] The rocks described as camptonites by Simpson and Glauert from the Philips River Goldfield appear to the writer to be really contact-altered amphibolites, Bull. 35, Geol. Surv. W.A., 1909, pp. 42-3.

The faggot-like areas give an aggregate polarisation colours like those of carbonates, but under high magnification this is seen to be due to the presence of numerous minute flakes of biotite. The small rods appear most often to be opaque, but on the edges of the section they are seen to consist of the green mineral described above. Finally there are a few elliptical areas like amygdules, consisting of coarse grained quartz and large flakes of biotite.

The interpretation of such a rock is impossible without field work to fix its geological nature, and in case it is an alteration product, to enable one to trace stages from some recognisable form. Assuming the small rods to be pseudomorphous after hornblende, the rock might represent a fine grained amphibolite or more likely a camptonite such as that described above. Such an assumption is, however, little removed from guesswork. The rock is certainly not a tachylite.

The remaining ten rocks, though not all from the same locality, form a distinct and related group. They show a graduated mineral composition, and differ chiefly in grain size. They are remarkable for the freshness of their felspars and pyroxene, and although the olivine and iron ores are at times somewhat altered, there is no sign of saussuritic, sericitic, chloritic or epidotic alteration products. They must, therefore, be assumed to be of much later age than the gneissose, and probably also the dyke rocks, just described. They are for the most part holocrystalline, coarse grained and almost black, the felspars being so transparent as to affect the colour of the rock very little. The mineral composition is that of gabbros or norites, but on account of the perfect ophitic structure displayed, the term dolerite is preferable. The more basic rocks contain much olivine, the most acid contain free quartz in micropegmatite, while the whole series is characterised by the

small amount of iron ores and a great richness in ferro-magnesian minerals, viz. olivine, hypersthene and enstatite augite. The following table shows the mineral composition, the rocks being arranged approximately in order of their basicity:—

| | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|
| Olivine ... ... | † | † | † | † | † | * | * | – | | |
| Hypersthene ... ... | † | † | † | † | † | † | † | – | | |
| Enstatite-augite ... | – | † | † | † | † | † | † | † | | |
| Augite... ... ... | – | – | † | † | | † | † | – | | |
| Pyroxene-perthite ... | – | † | – | † | † | – | † | – | | |
| Hornblende ... ... | – | – | – | – | – | – | * | – | | |
| Biotite... ... ... | * | * | – | * | * | – | * | * | | |
| Iron ores ... ... | † | * | † | † | * | * | * | † | | |
| Apatite ... ... | * | – | – | * | – | | – | – | | |
| Plagioclase ... ... | † | † | † | † | † | † | † | † | | |
| Orthoclase ... ... | * | * | – | * | * | – | – | – | | |
| Quartz... ... ... | – | – | – | – | – | – | – | * | | |

† An important constituent. * A minor constituent. – Absent.

7. *Near Camp* 9, 23/6/91. 8. *Hills near Camp* 5, 20/6/91. 9. *Zig Zag Range*, 15/7/91. 10. *Near Camp* 8, 23/6/91. 11. *Thirteen miles west of Depôt I*, 19/6/91. 12. *Cavanagh Range*. 13. *Cavanagh Range*, 29/7/91. 14. *Near Depôt I, Cap of Range two and a half miles distant*. 15. *Cap of Granite Range, Depôt I, Camp* 4, 9/6/91. 16. *Cavanagh Range*, 21/7/91.

The above table displays the interesting fact that while orthoclase and biotite are present in almost all the rocks, hornblende appears only in the acid rocks concomitantly with the disappearance of olivine.

The iron ores are seldom abundant, and exhibit variable relationships. In No. 7 they are quite idiomorphic to hypersthene and orthoclase, but present a broken outline towards plagioclase, to which they appear to be posterior. In other cases they are distinctly moulded on the plagioclase and also on the pyroxenes. In No. 7 the species is ilmenite, but in the others it appears to be a titaniferous magnetite, to judge from the octohedral sections and the very slight

leucoxenic alteration on the borders of some grains. A small amount of secondary magnetite is found in the olivine of some of the specimens.

Olivine occurs plentifully in the more basic rocks. Sometimes it is clear, with only a slight separation of iron ores along the cracks, and is a variety with an axial angle approximating 90° (No. 7), and occasionally shows a slight schiller structure (No. 11). In No. 14 it is of a violet colour and is always surrounded and apparently partially replaced by iron ores. In the other rocks, when present, it shows an incipient or complete alteration into a brown or green biotite-like mineral of high birefringence that may be referred to iddingsite, accompanied in No. 12 by a considerable amount of iron ores and talc. The olivine is sometimes of early crystallisation (Fig. 1), but is sometimes ophitic to the plagioclase (Figure 6, Plate XIV). It never shows perfect crystal outlines, but occurs in more or less embayed forms, which are sometimes cresentic when the mineral is enclosed in a pyroxene. There is in places a considerable amount of hypersthene interposed between the olivine and felspars.

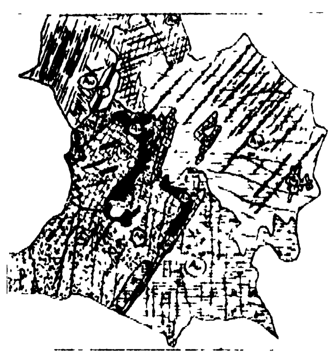


Fig. 1.—*Olivine dolerite with hypersthene and enstatite-augite. No. 13. Cavanagh Range. Crossed nicols. Magnification 15 diams.*

The pyroxenes are very interesting in their relations. A rhombic pyroxene referable to hypersthene on account of its optically negative character but with somewhat variable intensity of pleochroism, is abundant in the basic rocks. It is usually subordinate in amount to the monoclinic pyroxenes, but in No. 7 it predominates in

Figure 2.—*Polysomatic group of enstatite-augite with intergrowth of hypersthene. Dolerite, Cavanagh Range. Magnification 23 diams.*

typically ophitic forms. In some cases it veins the augite in a peculiar manner that suggests coarse intergrowths (Fig. 2) and at times is clearly intergrown with the enstatite-augite on a fine scale (Fig. 5, Plate XIV).

The monoclinic pyroxenes, though all optically positive, vary considerably in optical angle, from practically 90° to 0·4°. It has been shown by Wahl[1] that this variation is dependent on the amount of lime entering into the composition of the mineral. In normal diopside, with high axial angles, the proportion of CaO : MgO + FeO is nearly 1 : 1, but in a series of pyroxenes in which the proportion ofl ime is gradually less, the axial angle is correspondingly smaller, until it passes through 0° and the optic axes open out in a plane normal to the plane of symmetry, so that in certain cases the mineral is uniaxial for a given colour. For this series, which he supposes to consist of solid solutions of ordinary diopside or augite on the one hand, and clino-enstatite or clino-hypersthene on the other, Wahl has proposed the generic name of enstatite-augite, with specific names for different members of the series. Rosenbusch[2] has preferred to call the group magnesian-diopsides. These peculiar augites have been recognised in Australia so far

[1] Wahl, W., Die Enstatitaugite. Tsch. min. u. petr. Mitth. xxvi, (1907), pp. 1 - 31.

[2] Rosenbusch, H., Mikr. Phys., I, 2.

only by Osann[1] in a Tasmanian dolerite. They are fairly common, according to my observations, in the Mesozoic dolerite sills of Tasmania, specimens of which have been kindly given me for this purpose by Mr. Twelvetrees, Government Geologist, and slides prepared by Mr. R. Priestly. They are also not uncommon among the later dykes of dolerite and quartz-dolerite traversing the goldfields of Western Australia

Wahl[2] has also pointed out the presence of intergrowths of various pyroxenes with one another, and after the analogy of the felspar group has given them the name of pyroxene-perthites. As it has not been possible to obtain a copy of this paper in Sydney, the writer cannot make further comparisons between those observed in these rocks and those described by Wahl.

As the size of the optic axial angle can be observed only on suitably oriented sections, it is impossible by its observation alone to ascertain the relative amounts of common augite and enstatite augite. Moreover it is not uncommon to find that there are great variations of axial angle in the same crystal. Enstatite augite has often a characteristic basal striation and a peculiar alteration along the basal plane, which is sufficient to distinguish it from augite in the absence of such a striation in the latter. In the rocks under consideration, hypersthene curiously enough never shows schiller structures. The monoclinic pyroxenes are also in the finer grained rocks quite free of any such structures, while in the coarser rocks, in which rod-like inclusions both parallel to the A-pinacoid (diallagic schillerisation) and parallel to the basal plane are abundant, no distinction can be made out between the enstatite-augite and common augite in this respect.

[1] Osann, A., Ueber einem Enstatitaugit Führenden Diabas von Tasmanien. Centralbl. F. Min. etc., No. 23, pp. 705-11, 1907,

[2] Wahl, W., Analogien Zwischen die Pyroxen und Felspathgruppe. Quoted from memory. ? Ref. a Finnish Journal.

All the pyroxenes are clearly posterior both to the olivine and the felspar, embracing the latter in typically ophitic fashion (Fig. 6, Plate XIV, and Text Fig. 1). In general the hypersthene appears to be posterior to the monoclinic pyroxenes,[1] but in some cases is seen in parallel growth with them, and again is sometimes clearly intergrown with them, forming a pyroxene-perthite (Fig. 5, Plate XIV). The finer pyroxene-perthites are apparently homogeneous augites in ordinary light, but between crossed nicols they closely resemble micropegmatite. In the latter the intergrowth is too fine to permit the determination of both species of pyroxene, although one of them is often hypersthene.

Hornblende, a greenish variety, is confined to the more acid rocks, and in these to the exterior of the pyroxene grains. In Nos. 12 and 13, where it is fibrous and confined to the exteriors of the hypersthene, it may confidently be described as uralite. In Nos. 15 and 16, where it is compact, brownish-green, and occurs as crystallographic outgrowths on the pyroxene, it is more probably original, but in these also there is a subordinate amount of a paler and somewhat fibrous hornblende which is probably uralitic.[2]

Biotite occurs in small quantity in almost all the rocks. It is found only in ragged flakes, and in most cases surrounds or lies alonside the iron ore, from which it appears to have been derived by a partial resorption.

The felspars, which are the most abundant minerals, are for the most part glassy clear, but in some of the rocks the plagioclase has a milky brown appearance due to the

[1] *Cf.* Elsden, J. V., The St. David's Head 'Rock-Series.' Q J.G.S., LXIV, (1908) pp. 286-8.

[2] For a more detailed discussion of the writer's views on the distinction between uralite and primary hornblende, and the raison d'etre of the latter's occurrence, *cf.* Thomson, J. A., Petrological Notes to Bulletin 33, Geol. Surv, Western Australia, 1909, pp. 132-5.

presence of extremely minute inclusions, while the orthoclase is practically clear. The latter occurs in but slight amount in the more basic rocks, and is always interstitial to all the other elements, and generally crowded with needles of apatite. In those rocks containing quartz it is more abundant as an element of the micropegmatite. The plagioclase is a thoroughly basic variety with only at most a slight peripheral zoning of acid material. Its refractive indices are always greater than those of balsam and of quartz whenever a comparison is possible. Carlsbad, albite and pericline twinning are abundant, and the extinctions indicate, by Levy's method, basic labradorite and bytownite.

One of the rocks, No. 12, was kindly analysed by Mr. G. J. Burrows, in the geological department of the Sydney University. With it may be compared some similar analyses made on the same class of rock elsewhere.

| | I. | II. | III. | IV. | V. |
|---|---|---|---|---|---|
| $SiO_2$ | 51·55 | 50·55 | 50·76 | 52·49 | 8592 |
| $TiO_2$ | 0·53 | 0 05 | 0·46 | 0·62 | 66 |
| $Al_2O_3$ | 18·85 | 17·16 | 16·83 | 16·44 | 1848 |
| $Fe_2O_3$ | 0·32 | 1·04 | 4·16 | 2·60 | 20 |
| FeO | 6·77 | 3·40 | 4·45 | 5·30 | 940 |
| MnO | 0·13 | 0·19 | 0·69 | trace | 18 |
| MgO | 7·09 | 9·97 | 10·09 | 6·18 | 1772 |
| CaO | 14·04 | 14·77 | 11·30 | 11·71 | 2507 |
| $Na_2O$ | 0·63 | 1·62 | 0·97 | 2·06 | 102 |
| $K_2O$ | 0·08 | 0·11 | 0·06 | 1·09 | 9 |
| $H_2O$ | 0·11 | 0·36 | 0·14 | 1·42 | |
| $H_2O$ | 0·04 | 0·12 | ... | 0·15 | |
| $P_2O_5$ | trace | ... | none | trace | |
| $CO_2$ | none | ... | ... | ... | |
| $FeS_2$ | none | 0·17 | ... | ... | |
| | 100·14 | 99·51 | 100·06 | 99·91 | |
| Analysis, | Burrows. | Simpson. | Ditrich. | Harrison. | |

I. Cavanagh Range.
II. "Norite," Norseman, W. A., Bull. 21, Geol. Surv. W.A. 1906, p. 119.
III. "Diabase," Barina District, British Guiana, Rep. Geol. N.W. District, II, p. 6, 1898.
IV. Hunnediabase, Launceston, Tasmania, Quoted in Ann. Rep. Dept. Mines, 1908.
V. Molecular proportions of I.

The analysis is interesting in the first place as adding to our information of the chemical composition of the Hunnediabase. Typical quartz-dolerites (Kongadiabas) show in general a lower proportion of alumina than normal rocks of the same silica percentage, whereas this rock possesses, if anything, a higher figure. These peculiarities are due, in the former to the presence of free silica, in the latter to the abundance of a very basic felspar, for anorthite is relatively richer in alumina than albite. It is somewhat surprising to find a pyroxene poor in lime crystallising from a magma so rich in that element, but a calculation shows that after apportioning lime to alumina to form anorthite, there is relatively little non-felspathic lime. The mineral composition may be calculated as follows:—

| | | | | |
|---|---|---|---|---|
| Quartz | | | | 6·23 |
| Orthoclase | | 0·49 | Felspar | 54·12 |
| Albite | 5·34 | Plag. 53·63 | | |
| Anorthite | 48·29 | | | |
| $CaSiO_3$ | | 8·93 | Pyroxene | 38·16 |
| $MgSiO_3$ | 17·72 | | | |
| $MnSiO_3$ | 0·24 | 29·23 | | |
| $FeSiO_3$ | 11·27 | | | |
| Magnetite | 0·46 | | Iron ores | 1·47 |
| Ilmenite | 1·01 | | | |
| $H_2O$ | 0·15 | | | |
| | 100·13 | | | |

According to the norm of the American authors there is 17·86 diopside and 20·30 hypersthene. In the mode, however, there is not so much hypersthene, and most of the metasilicate is contained in an augite poor in lime. It is difficult to account for the presence of quartz in the norm in a rock from which olivine has crystallised.

The analysis is fairly closely paralleled by that of the "norite" of Norseman, which is a very similar rock as is pointed out below. It contains, however, a higher proportion of hypersthene. The diabase from British Guiana, of which I have not been able to compare the mineral composition, also agrees sufficiently well to place it in the same class, but with a higher percentage of soda there is a distinct drop in the amount of lime, reflected by a smaller drop in the alumina. The Hunnediabase from Launceston shows the same differences and also lower iron and magnesia percentages, due probably to the absence of olivine. In spite of these minor differences, the four analyses obviously show a close agreement.

The nomenclature of this group of rocks is a matter of difficulty. Overlooking the presence of hypersthene, those rocks with enstatite-augite and without quartz come under Rosenbusch's group of Hunnediabase; those with quartz, under his group of Kongadiabase, while No. 7 may be described as an ophitic norite or a hypersthene diabase. The writer prefers, however, to call them all dolerites, indicating their special characters by the prefixing of the names of those minerals not common to all dolerites, *e.g.* hypersthene enstatite-augite olivine dolerite. This method though admittedly clumsy, gives due weight to each element of composition.

The affixing of correct names to the rocks is, however, only a matter of secondary importance. What is more important is the recognition of this group of rocks in

Central Australia. The nearest allies known to the writer are to be found in the dyke at Norseman already referred to. A study of eight specimens from different parts of the dyke, kindly presented to the writer by Mr. A. Gibb Maitland, Government Geologist of Western Australia, shows a series of rocks ranging from hypersthene through olivine norite to quartz norite, with enstatite-augite and pyroxene-perthite in many of the specimens. The dyke runs east and west through a series of amphibolites and schists that lie in N.E-S.W. belts. It is distinctly the youngest of the solid rocks of the field, later even than the granites and accompanying quartz-porphyries, which run in the plane of the foliation. In these respects, and in its petrological characters (though not its coarseness) it is typical of a large series of dykes traversing the rocks of the different gold-fields. These "later dykes" as the writer proposes to term them, are in many fields distinct from the gold bearing lodes, which they intersect and fault. The areas occupied by them in Central Australia may therefore be presumed to be non-auriferous. It does not necessarily follow, however, that the whole area is non-auriferous. Owing to differential erosion, these later dykes frequently stand up above the softer auriferous rocks, and afford the best opportunities of collecting specimens. So it may be that in central Australia the later dykes are intrusive through auriferous rocks also. The evidence on this point is quite non-conclusive.

The presence of enstatite-augite and quartz-dolerites in Central and Western Australia leads to theoretical considerations of more than local interest. Though those described are fairly deep-seated and approaching gabbros in crystallisation, there are petrologically similar rocks of finer grain among the later dykes of Western Australia known to the writer which clearly show the close connec-

tion between the group and the Mesozoic dolerites of Tasmania before alluded to. Further, the dolerites and quartz dolerites of Victoria Land, Antarctica, also possess, according to the writer's observations, the same petrological peculiarities, and in particular the minerals enstatite-augite and pyroxene-perthite. Though the writer's observations on the Karroo dolerites of South Africa have not been sufficiently extensive to allow the same affirmation to be made, Wahl has shown[1] that the 'diabase' of Richmond originally described by Cohen[2] contains enstatite-augite, and it is reasonable to suppose that this mineral has a wide occurrence in South Africa.

The Tasmanian and South African rocks are definitely known to be of late Mesozoic or early Tertiary age. There is no evidence so far produced to show that the others are not of the same age. They all occur in the remaining horsts of the foundered Gondwana Land, and the question arises whether they do not point to the presence of an immense magma or to a series of similar magmas, which in Mesozoic times underlay the old Gondwana Land, parts of which were forced up by the earth movements which led to the breaking up of the continent.

Mr. Benson has kindly drawn my attention to a paper in which Prior[3] has already made a similar suggestion, *i.e.* he suggests that the dolerites of Zululand and Victoria Land are of the same age, and further points out the curious association of these rocks on the mainland in each place with later alkaline rocks in outlying islands. This observation might, with reservation, on the island-occurrence of the alkaline rocks be equally applied to Tasmania. But

[1] *Loc. cit.*, pp. 29-30.

[2] Geognostisch-petrographische Skizzen aus Sud-Africa, Neues Jahr. f. Min. etc. 1887, B.B., p. 234.

[3] Prior, G. T., Petrographical Notes on the Dolerites and Rhyolites of Zululand, Ann. Natal Mus. II, 1910, p. 152.

it does not hold good for Western Australia, where alkaline rocks are quite unknown, nor to New Zealand, where the same alkaline series as that of Erebus is well displayed, but where quartz-dolerites are so far unknown.

In opposition to the suggestion of a petrographical magma common to the whole of Gondwana Land, it may be urged that the class of rocks relied on, viz. quartz-dolerites with hypersthene or enstatite-augite are not by any means confined to remains of that ancient continent, but are equally common in British Guiana, Great Britain, Canada, etc. That would be to imply, however, that similar petrographical provinces could not exist in different parts of the earth. A stronger objection is furnished by certain theoretical views on the mode of formation of these rocks. It has been suggested by Daly[1] that quartz-gabbros and the commonly associated granophyres are formed by the acidification of gabbros by the assimilation of the surrounding walls. Tyrell[2] has elaborated this view with special regard to quartz-dolerites, and suggests further that they represent a critical stage in assimilation, in that they are almost entirely made up of intergrowths of related minerals, and have reached the limit of saturation of a basic magma with quartz. Both these writers totally fail to explain the excess of magnesia and iron over non-felspathisable lime which is necessary for the formation of hypersthene or enstatite-augite. Whether we admit with them that quartz-dolerites have arisen by the assimilation of acid material by a basic magma. or agree with Vogt that they have arisen by differentiation as an "anchi-eutectic" rock, we must still postulate that the primary magma had funda-

[1] Daly, R. A., The Secondary Origin of Certain Granites, Am. Journ. Sci., xx, 1905, pp. 185 - 216.

[2] Tyrell, G. W., Geology and Petrology of the Intrusions of the Kilsyth-Croy District, Dumbartonshire. Geol. Mag., Dec. 5, Vol. VII, 1909, pp. 299 - 309 and 359 - 366.

mental chemical peculiarities to allow it to give rise to a secondary magma capable of producing these minerals, instead of common augite. It is this chemically peculiar primary magma which is necessary for the establishment of a petrographical province.

A further line of evidence which strengthens the writer's suggestion is the recurrence of quartz-dolerites at different geological ages in some of the above fragments of Gondwana Land. Owing to their degree of alteration, it is not possible to assert that the older groups also contained enstatite-augite, but analyses support the view. This phase of the subject is too extended to discuss at length here, but the following facts may be instanced. Among the Western Australian amphibolites of supposed pre-cambrian age there are rocks which can be shown to be merely uralitised and saussuritised quartz-dolerites.[1] Henderson[2] has described similar rocks from the Transvaal, which may be assumed to be much older than the Karroo dolerites.

In India, the important fragment of Gondwana Land from which Mesozoic quartz-dolerites have not been noted, there is a well known occurrence of the rock in the Cuddepah, and in these Wahl has shown the presence of enstatite-augite. But there is also in the Archæan of India the peculiar group of charnockites which exhibit, not indeed the same structural peculiarities but very similar chemical relations, viz. a high proportion of magnesia and iron compared to non-felspathisable lime combined with an excess of silica.[4]

[1] Thomson, J. A., Petrographical Notes to Bull. 33, Geol. Surv. W.A., 1909, pp. 137, 145, 151, and 156.

[2] Henderson, J. A. L., Petrograpical and Geological Investigations on certain Transvaal Norites, Gabbros and Pyroxenites, London, 1898, pp. 29 - 33.

[3] Holland, T. H., On Augite Diorites with Micropegmatite in S. India. Q.J.G.S., LIII, (1897) p. 405 Wahl, *loc. cit*

[4] Holland, T. H., The Charnockite Series, a group of Archæan Hypersthene Rocks in Peninsular India. Mem. Geol. Surv. India, XXVIII., Pt. 2, pp. 119 - 249, 1900.

Whether the similar recurrence of these rocks at different periods of geological history will be found so abundantly elsewhere as to invalidate the force of this argument, so far as it applies to the rocks of Gondwana Land, remains for the future to disclose. In so far as it applies to Australia, it opens up a fruitful field of enquiry for Australian petrologists.

NOTE.—Since the above was written, an important paper by Dewey and Flett has made suggestions that to some degree undermine the above views.[1] In effect, they propose to recognise besides the well known Atlantic and Pacific suites of rocks yet a third known as the spilitic, and geographically associated with districts of long continued and gentle subsidence. The rocks characterising the suite are picrite, diabase (often albitised), minverite, quartz-diabase, keratophyre, soda felsite and albite granite. The most striking chemical peculiarities of the group are the richness in soda compared to potash and lime, not indeed always to be seen in the original minerals, but betrayed by the juvenile albitisation that the rocks have undergone.

Quartz-dolerites, then, are claimed by them as belonging, at least in part to the spilites, both on account of the albitisation which they sometimes exhibit and of their geological relationships with other members of the suite, whereas in the ideas put forward above, they are attached to the charnockite suite on account of their relative richness in iron and magnesia. It must be admitted at once that the above authors have a far stronger case for their general view, based as it is on a much greater body of observation. There are even features in Western Australia that give support to the possibility of the spilite suite being

[1] Dewey, H., and Flett, J. S., British Pillow-lavas and the Rocks associated with them. Geol Mag., Dec. 5, Vol. VIII, 1911, pp. 202-9 and 241-8.

developed there, viz. the occurrence of albite granites and the presence of albitisation amongst the older (amphibolitised) quartz-dolerites. If, on the other hand, the commonly occuring rock types are correctly accounted for as anchieutectic rock, as many authors are now willing to believe, there would be a tendency for the development of similar rocks from widely different primary magmas. That such 'diphiletic'[1] rocks are present in the case of the Atlantic and Pacific suites has been consistently denied by Rosenbusch, but even he is unable to ascribe most basalts to one or the other suite, and other observers believe in the possibility of diphiletic rocks. It would not do to push this possibility too far in connection with the views suggested above, or the primary chemical peculiarity postulated above would not be deducible from such a diphiletic anchieutectic rock.

## Summary and Conclusions.

A series of seventeen rocks collected by the Elder Scientific Exploring Expedition from the neighbourhood of the eastern boundary of Western Australia are described in detail, and compared with the rocks of the Western Australian goldfields. Only one resembles the immediate country of the auriferous veins. Two are probably to be referred to the gneiss formation. The remainder are dyke rocks; they include a camptonite, the first undoubted occurrence of this type in Western Australia, and a number of very fresh intrusive dolerites of considerable petrological interest, especially in that they are the first rocks on the Australian mainland in which enstatite-augite and pyroxene-perthite have been recorded. A comparison of these rocks with the later dykes of Western Australia and the dolerite sills of Tasmania, Antarctic and South Africa

[1] I am not aware whether the term diphiletic has been used before in this sense. It was suggested to me in conversation by Dr. J. S. Flett.

is made, and the suggestion is put forward that they are of the same age and magmatically related.

The results obtained from this small collection are sufficient to show that the whole official collection, consisting of some hundreds of rocks is worthy of a fresh examination in the light of the recent knowledge acquired in the Western Australian goldfields. Presumably the collection is in the possession of the Royal Society of South Australia.

### EXPLANATION OF PLATE XIV.

Fig. 1. Banded norite, Fraser's Range, Western Australia. Natural light. Magnified 15 diameters.

" 2. Hornblende granite-gneiss, Blyth Range, Central Australia. Crossed nicols. Magnified 15 diams.

" 3. Granulite, Barrow Range, Central Australia. Natural light. Magnified 15 diams.

" 4. So-called tachylite, Cavanagh Range. Natural light. Magnified 15 diams.

" 5. Pyroxene-perthite in quartz dolerite, No. 14, Near Depôt 1. Crossed nicols. Very highly magnified.

" 6. Hypersthene olivine dolerite. showing ophitic structure of both olivine and hypersthene towards felspar. No. 8, Hills near Camp 5, 20/6/91. Natural light. Magnified 15 diams.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

[*From the Proceedings of the Linnean Society of New South Wales, 1913, Vol. xxxviii., Part 1, April 30th.*]

# THE GEOLOGY OF THE PERMO-CARBONIFEROUS SYSTEM IN THE GLENDONBROOK DISTRICT, NEAR SINGLETON, N.S.W.

By A. B. Walkom, B.Sc., Linnean Macleay Fellow of the Society in Geology.

(Plate xiv., and four text-figures.)

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(Plate xiv., and four text-figures.)

The district treated of in this paper, lies from 5 to 15 miles E. by N. from Singleton. It contains two units of Permo-Carboniferous rocks, namely, a small basin about 2 miles N.E. of Mt. Tangorin, with a diameter of approximately 3 miles; and the northward extension, from the Hunter River District, of the Upper Coal-Measures and Upper Marine Series along Glendon Brook and Westbrook Creek.

*Previous Literature.*—In his memoir on "The Geology of the Hunter River Coal Measures," Professor David* has described the outcrop of rocks belonging to the Lower Marine Series and Greta Coal-Measures in Parishes of Tangorin and Stanhope, and has indicated some of the outcrops on a sketch-map.

* Mem. Geol. Surv. N. S. Wales, Geology, No.4, 1907, pp.188-189.

The Coal-Measures at Westbrook Creek were reported on by the late C. S. Wilkinson,* and also have been examined by Professor David †

The ironstone at Westbrook Creek has also been mentioned in J. B. Jaquet's memoir on "The Iron-Ore Deposits of New South Wales."‡

*Physiography, etc.*—The knot of hills round Mt. Tangorin is composed of hard resistant rocks, mostly eruptive, of Carboniferous age. Similar rocks are also responsible for the range which trends about E.N.E. from Tangorin, although they do not form the summit of the range at all points. A part of the top of the range, for a distance of about 2 miles E.N.E., from portion 96, Parish of Stanhope, is made up of massive conglomerates and sandstones of Upper Marine age. These sandstones and conglomerates extend northwards nearly to the southern boundary of portion 90, Parish of Tangorin, and form a number of flat-topped hills. Less resistant rocks (of Lower Marine age) intervene between these conglomerates and sandstones and the Carboniferous rocks, and the denudation of these is responsible for the gap in the range at Cranky Corner. To the west of Brook's Mountain, the country becomes undulating. The rocks in this part belong to the Upper Coal-Measures and Upper Marine Series, which have been let down to the level of the Carboniferous rocks by heavy faulting.

A point worthy of note is the salinity of the creek-waters in the neighbourhood of the Tangorin Range. This is brought to one's notice, during dry weather, by the fact that the gravels and creek-beds are often covered with a white saliferous deposit, when there has been a good deal of evaporation.

*General Geology.*- Stratigraphically, the rocks represent two systems, (A) Carboniferous, and (B) Permo-Carboniferous.

(A) CARBONIFEROUS.—There are two distinct divisions of the Carboniferous rocks, separated from one another by the Webber's Creek fault, which extends in a general E.-W. direction for about 10 miles, and throws to the south.

* Ann. Report Dept. Mines N. S. Wales, 1884, p.151.

† *Op. cit.*, pp.274-277.

‡ Mem. Geol. Survey N. S. Wales, Geology, No.2, 1901, p.111.

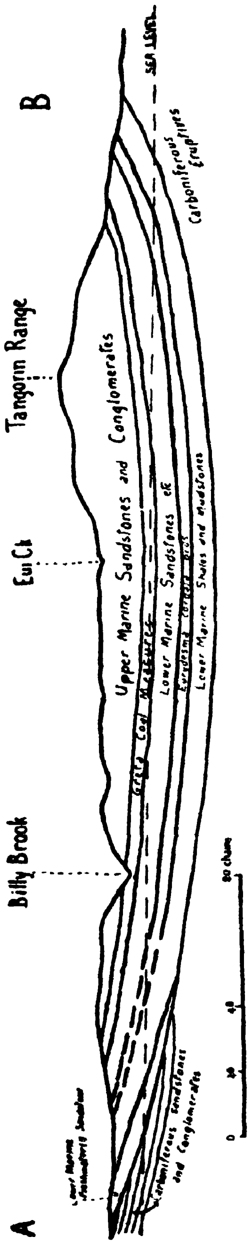


Fig. 1.—Section along AB.

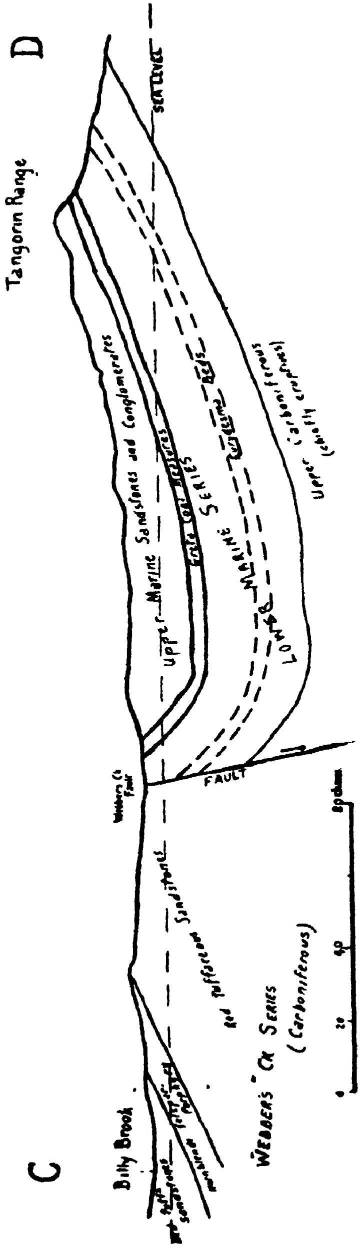


Fig. 2.—Section along CD.

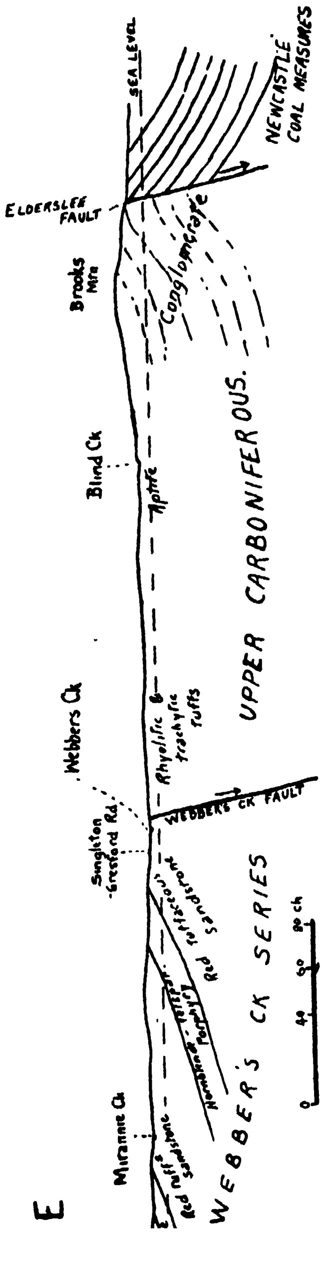


Fig.3.—Section along EF.

The older of these two divisions, that on the northern side of the fault, I have called here the Webber's Creek Series. This series has been examined, at intervals, for about a distance of 10 miles in an E.-W. direction, and extends for quite 5 miles north from the fault, which forms its southern boundary. The series consists of sandstones and shales, with contemporaneous lava-flows. The sandstones are more of the nature of arkoses, being composed mostly of grains of orthoclase with a smaller amount of quartz, hornblende, and biotite. In places, in these arkose sandstones, there are small bands of chocolate shale. The sandstones are conglomeratic in places, and, where this is the case, they contain pebbles of such rocks as banded rhyolite, andesite, aplitic granite, porphyrite, quartzite, etc. The lava-flows associated with this series consist of dacite and hornblende-felspar porphyry. There does not seem to be any doubt but that these flows are contemporaneous and not intrusive, although no very definite evidence is forthcoming on that point. They form long, comparatively narrow outcrops, roughly parallel to the strike of the arkose sandstones, and, being harder than the latter,

they form lines of hills running in a general E.-W. direction. These hills have a relatively steep slope on the southern side, and slope more gently away to the north, showing that they dip to the north in the same way as the sedimentaries do.

This series of rocks appears to be similar to part of the Upper Carboniferous Series described, some distance further to the east, by Mr. J. B. Jaquet. Part of his description of the latter series is: "The formation comprises sandstones, claystones, limestones, tuffs, cherty shales, and intercalated lava-beds. The sedimentary rocks are in part marine, and in part freshwater. *The great bulk of the rocks consist of coarse-grained tuffaceous sandstones, which do not contain recognisable organic remains; so that one is unable to determine whether they are marine or freshwater.*"*

The latter part of this description might be applied equally well to the series under consideration here. I have not seen specimens of the Clarencetown Series, but in discussing the subject with Professor David, he pointed out the great similarity, lithologically, between specimens of the Webber's Creek Series and the Upper Carboniferous rocks near Clarencetown.

Another point which emphasises the resemblance to the Clarencetown Series is the fact, mentioned to me by Mr. Frank Drinan, of Glendon Brook, that, in the creeks in the north-eastern part of the area shown on the accompanying map, the sands which accumulate in the beds of the creeks often contain a notable percentage of ironstone.

No fossils have been found in this series, so that it is uncertain whether they are marine or freshwater. If, however, as seems to be the case, they belong to the same series as the Clarencetown rocks, they are probably freshwater.

The other series of Carboniferous rocks is developed to the south of the Webber's Creek fault, and is called here the Tangorin Series, on account of the bold outcrop at Tangorin Trig. Station. They are bounded on the west by the northward extension of the fault named, by Professor David, the Elderslee Fault. They extend as far east as the district has been examined, and no doubt are con-

* *Op. cit.*, p. 64.

tinuous with the Carboniferous series at Hudson's Peak. They surround, almost completely, the isolated basin of Permo-Carboniferous rocks at Cranky Corner. They consist of a varied series of eruptives—rhyolite, trachyte, dacite, andesite, pitchstone, etc., and also rhyolitic and trachytic tuffs, tuffaceous sandstones and conglomerates. Professor David has found an abundance of *Rhacopteris* in some of the tuffs on the road just south of Cranky Corner, so that there is no doubt that they belong to the same series (Upper Carboniferous) as those Carboniferous rocks occurring further south, at Winder's Hill and Pokolbin.*

No boundaries of these Carboniferous rocks have been surveyed, except where they are in contact with rocks of different age, but field-names have been placed on the map at points where they have been observed.

(B) PERMO-CARBONIFEROUS.—There are two separate occurrences of Permo-Carboniferous rocks in the district, namely, (*a*) the Cranky Corner Basin, (*b*) the series west of the Elderslee fault.

(*a*) *The Cranky Corner Basin.*—In this area, there is a development of some 1,850 feet of Permo-Carboniferous strata, made up approximately of 900 feet of Lower Marine Series, 150 feet of Greta Coal-Measures, and 800 feet of Upper Marine Series. An examination of the dips at once shows that these strata form a somewhat triangular-shaped basin. They are surrounded, for the greater part, by the Tangorin Series, except on a portion of their northern side, where they have been brought into contact with the Webber's Creek Series by the Webber's Creek fault. They are unconformable above the Carboniferous System, there being differences generally of 30° to 40° in the directions of strike, where Carboniferous and Permo-Carboniferous sedimentary rocks occur close together. Near portions 14 and 11, Parish of Stanhope, the Carboniferous conglomerates strike about N.-S., and dip easterly; while the Permo-Carboniferous rocks strike 327°, and dip at 14° in direction 57°. Near Tamby Creek, about portion 98, Parish of Tangorin, the Carboniferous conglomerate strikes 140°, dipping

* Journ. Proc. Royal Soc. N. S. Wales, xlv., 1911, pp.379-408.

south-westerly, and the Permo-Carboniferous rocks strike 100° dipping southerly.

(i.) Lower Marine Series.—In portions 35 and 98, Parish of Tangorin, just opposite portion 81, there is a small outcrop of rather coarse sandstone containing remains of plant-stems. This is resting unconformably on Carboniferous conglomerates, and is the lowest member of the Permo-Carboniferous System found in the district. The outcrop, however, is only of limited extent, being cut off by the Webber's Creek fault to the west, and thinning out between the Carboniferous conglomerates, and the overlying mudstones towards the south-east. From its lithological character, and from the presence in it of plant-stems, and also since it is the lowest member of the Lower Marine Series developed here, it seems very probable that it is to be correlated with the sandstone which is immediately above the glacial beds in the Lochinvar District. It attains a thickness of about 100 to 150 feet.

Next above this sandstone, there is a thickness of some 300 feet of bluish shaly mudstones. These can be traced, almost continuously, nearly right round the basin. About half-way up in these mudstones, there is an horizon of hard limestone-concretions containing fossils. These are chiefly *Fenestella*(?) sp., and a small brachiopod shell (? *Dielasma*). This bed with Fenestellidæ can be seen at three localities in the Parish of Stanhope, namely, (1) on the W.-E. road in portion 66, (2) in portion 46, and (3) in the creek in portion 50. The mudstones are fossiliferous, but most of the fossils appear to be in the upper part, *i.e.*, above the limestone-concretion horizon. Some of the fossils from these mudstones are:—

| | |
|---|---|
| *Spirifer duodecimcostata.* | *Aviculopecten tenuicollis.* |
| *S. tasmaniensis.* | *A. englehardti.* |
| *S. stokesi.* | *Pachydomus.* |
| *Martiniopsis subradiata.* | *Ptycomphalina trifilata.* |
| *Chænomya* sp. | *Hyolithes lanceolatus.* |

The best locality for collecting these, is in portion 10, Parish of Stanhope, on the western slope of the hill, between the creek and the eastern boundary of the portion.

In portion 91, Parish of Stanhope, there is a development of basalt and breccia in this series. This may represent a centre of volcanic activity, which was responsible for the tuffaceous nature of the sandstones next to be described.

Following the mudstones, there is a thickness of about 120 feet of rather coarse tuffaceous sandstone. Good outcrops occur, the best being those in portions 8, 96, 78, 76, and 74, Parish of Stanhope. It is thus seen that this sandstone occurs continuously on the western and south-eastern sides of the basin, but has not been observed to outcrop on the northern side. This absence on the northern side is due to the presence of the Webber's Creek fault. The sandstone contains numerous marine fossils, there being, in places, regular banks of such thick-shelled molluscs as *Eurydesma cordata, Platyschisma*, etc., indicating turbulent, shallow-water conditions during the deposition of the beds. The fossils present in this sandstone include—

| | |
|---|---|
| *Spirifer duodecimcostata.* | *Pachydomus.* |
| *S. tasmaniensis.* | *Scaldia*(?). |
| *Martiniopsis subradiata.* | *Platyschisma oculus.* |
| *Aviculopecten mitchelli.* | *Mourlonia.* |
| *A. tenuicollis.* | *Ptycomphalina* |
| *Eurydesma cordata.* | *Hyolithes lanceolatus.* |

In appearance, this sandstone is sometimes very similar to that of Harper's Hill, and the similarity is increased by the occasional presence of andesitic boulders, with numerous amygdules of secondary silica, calcite, etc.

The remainder of the Lower Marine Series consists of about 330 feet of mudstones, sandstones, and conglomerates, in which fossils appear to be very scarce. At Eui Creek and Billy Brook, these are somewhat hardened and jointed, probably as a result of their proximity to the Webber's Creek fault.

(ii.) Greta Coal-Measures.—Above the Lower Marine Series, the Greta Coal-Measures are developed. They consist mostly of the sandstones and conglomerates typical of these measures, and there are also developed some beds of a brownish shale, as well as at least one coal-seam. The outcrop can be traced continuously round its

northern part, from portion 41 to portion 29, Parish of Stanhope, but the remainder is somewhat less certain. However, in portions 70 and 96, Parish of Stanhope, there is a conglomerate not unlike the Greta conglomerate, associated with a soft brownish and yellowish sandstone containing indeterminate plant-remains, and it is not unreasonable to put these down as belonging to these measures, more especially as they occur at localities where one would expect to find the Greta Measures. In portion 42, Parish of Stanhope, there are some shaly beds which contain plant-leaves. Along the northern part of the outcrop, and where it is close to the Webber's Creek fault, the dips are considerably higher than they are a short distance to the east or west, where they are not so close to the fault-line.

Coal is developed in these measures, and actual outcrops can be seen in Kangaroo Creek, on portion 90, Parish of Tangorin, and also in Billy Brook, on portion 26, Parish of Stanhope.

At the Kangaroo Creek outcrop, Professor David has measured a section of the seam as follows*:—

| | |
|---|---|
| Roof. | Conglomerate containing pebbles up to 3 or 4 inches in diameter. |
| 0ft. 6in. | Hard bituminous coal. |
| 1ft. 8in. | Clay shale. |
| 0ft. 8in. | Carbonaceous sandstone. |
| 0ft. 9in. | Hard bituminous coal. |
| 0ft. 2in. | Band of pebbly sandstone. |
| 1ft. 3in. | Hard bituminous coal. |
| 0ft. 6in. to 1ft. 0in. | Band of fine conglomerate and sandstone, carbonaceous in places and clayey. |
| 4ft. 0in. | Hard bituminous coal with pitchy lustre on freshly fractured surfaces. This coal approaches a cannel coal in composition. |
| 0ft. 6in. | Coaly shale. |
| 10ft. 0in. | Coal and bands. |

Mr. Frank Drinan, of Glendon Brook, very kindly piloted me to the outcrop in Billy Brook. The position of this outcrop has been fixed fairly closely. It is in the bed of the creek, and the bearing

* *Op. cit.*, p. 188.

from it to the western corner of portions 27 and 28, Parish of Stanhope, is 120½°. The coal is uncovered there, in the creek, for about six feet, and Mr. Drinan assured me that the seam used to outcrop at a position he pointed out to me, but which is now covered with débris; this point is some 10 to 15 yards further downstream. As the seam is dipping about south at 16°, this would indicate (if the two points represent outcrops of the same seam) a thickness of approximately 11 to 13 feet of coal and bands. This thickness corresponds very well with that mentioned above, and the two outcrops (Kangaroo Creek and Billy Brook) are probably of the same seam. As this outcrop (Billy Brook) was under water at the time of my visit, it was not possible to obtain specimens suitable for analysis, but from the pieces which could be got, the coal appears to be a hard, bright, bituminous coal of good quality. The position and extent of the actual outcrops depend on weather-conditions a good deal. Between my two visits to Kangaroo Creek (about three months apart), there was considerable rain, and much of the outcrop, as first seen, was covered with soil washed down the creek-bank.

At a number of other points in the neighbourhood, pieces of coal have been observed, washed into the creeks after heavy rains, *e.g.*, in Eui Creek above Mr. Peter's house, in portion 42, and in Billy Brook about portion 40, Parish of Stanhope. That these come from the same measures, there is no doubt, but the outcrops are probably covered over by surface-soil. The outcrop in Billy Brook is due to the creek having cut down through the overlying sandstone, isolating a part of it, and exposing the Greta Coal-Measures along the creek-bed. (See Section, Fig. 1, p. 148).

(iii.) The Upper Marine Series.—Above the Greta Coal-Measures, there is a series of massive sandstones and conglomerates. Marine fossils are very scarce in them, but, in the lower part, fragments of a Conularia (*C. inornata*) were found. These sandstones are, then, probably the equivalents of the lower part of the Branxton beds of the Upper Marine Series. The following is a vertical section of the Permo-Carboniferous rocks, as developed in this area (Fig. 4, p. 156).

(*b*) *Permo-Carboniferous Rocks west of the Elderslee Fault.*— The Elderslee fault, with a throw of nearly 6,000 feet to the west, brings the Upper Coal-Measures down against the Carboniferous rocks, just to the west of Brook's Mountain. In these Upper Coal-Measures, there are a number of coal-seams, which outcrop at intervals along Glendon Brook and Westbrook Creek. The series there consists chiefly of interbedded sandstones and conglomerates, with which there are also coal-seams, bands of ironstone, and occasional dolomitic bands. The ironstone is concretionary, and the bands vary from 1 inch to 15 inches in thickness. At the centre of the concretions, there is often a cavity in which quartz-crystals have grown. From the outcrops of the strata, Professor David* has calculated a descending vertical section, in which there are eighteen coal-seams varying from 3 to 27 feet in thickness. The measures in this part (Westbrook Creek), dip to the east, at angles up to about 70°, the very high angles of dip being at the extreme west of the occurrence of the series. The reason for these steep easterly dips is explained by their occurrence close to the Greta fault, which has a throw, at this point, of some 1,500 feet to the east, and forms the western boundary of these Upper Coal-Measures. Thus the Upper Coal-Measures here occupy an area of subsidence between two heavy faults, *i.e.*, it is a senkungsfeld-area. They do not extend any dis-

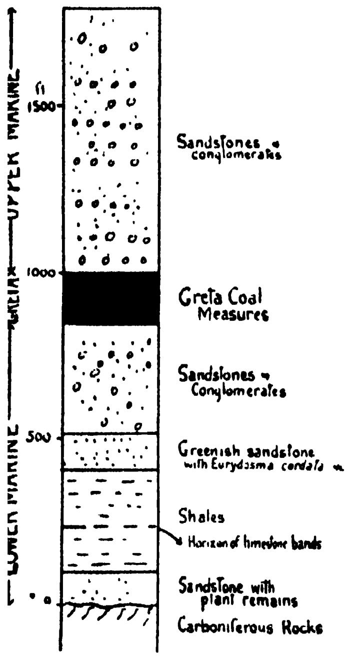


Fig. 4.—Vertical Section of the Permo-Carboniferous rocks.

* *Op. cit.*, pp. 275-276.

tance to the north, the northern boundary being formed by the Webber's Creek fault. This is shown by the fact, that the great majority of the boulders in the gravels brought down by Westbrook Creek and its tributaries, consist of eruptive rocks (chiefly porphyries, and dark-coloured, fine-grained rocks) and tuffs. On the west of the Greta fault, the Upper Marine Series are found, and they extend away westwards, past Singleton, until they disappear under the Rix's Creek Coal-Measures.

Immediately next the fault, there are shaly and sandy mudstones, with numerous erratics. These dip towards the east, and belong to the Crinoidal Beds, being part of the eastern arm of the Belford anticline. Some of the erratics are quartzites containing fossils. To the north, these beds extend some considerable distance I followed them along the Dyrring Road, to a point about 4 miles north of the village of Sedgefield.

*Faulting.*—In this area, there are three very heavy faults. Two of them are northward continuations of faults described by Professor David in the Hunter River District,* namely, the Greta and Elderslee faults, and, in each case, the throw has increased towards the northern end of the fault. The third has a roughly east-west trend, and throws to the south. It has been called here the Webber's Creek fault. The Greta fault has swung round from having a S.E.-N.W. trend to almost N.-S., and here has a throw of about 1,500 feet to the east, bringing the Upper Coal-Measures down into contact with the lower part of the Crinoidal Shales of the Upper Marine Series. The Elderslee fault strikes a little to the west of north, and has a throw of nearly 6,000 feet. The Carboniferous rocks, near the fault, are conglomerates, and rhyolitic and trachytic tuffs of Upper Carboniferous age, while, on the downthrow side, are rocks of the Upper Coal-Measures. At this point, then, all the rocks of the Lower Marine Series, Greta Coal-Measures, and Upper Marine Series that have been developed in the district, are faulted out of sight. That both the Lower Marine Series and Greta Coal-Measures were developed to some extent, is indicated by their presence at Cranky Corner, with a thickness

* *Op. cit.* pp. 302-304.

of about 1,000 feet; the Upper Marine Series have practically their full development (4,800 feet) not far away, so it seems not unreasonable to put the throw of the fault somewhere in the neighbourhood of 5,800 feet. The Webber's Creek fault trends roughly E.-W. in its western extension, and swings round to a S.W.-N.E. trend towards its eastern end. It extends, on the map, from near Westbrook to near "The Gap," on the road from Singleton to Gresford. It is an extensive fault, and its existence is indicated mainly by the following points:—

(*a*) The southern boundary of the Webber's Creek Series is a fairly regular line, and that Series is in contact with beds of different ages at different points, namely, Upper Carboniferous at Tamby Creek, Permo-Carboniferous from Tamby Creek to One-Tree Hill, Carboniferous again from there to the Elderslee fault, and then Upper Coal-Measures at Westbrook Creek. The fact that all these different series are cut off on their northern side, in a fairly regular line, favours the existence of a fault.

(*b*) Where the Permo-Carboniferous rocks approach close to the Webber's Creek Series (at One-Tree Hill), they have very high dips to the south, while a short distance to the west, where they are not so close, the dip is much less.

(*c*) Also where the Permo-Carboniferous shales are nearest the Webber's Creek Series, there is a slight amount of metamorphism of the shales, which might easily have been the result of faulting.

(*d*) No tuffaceous sandstones, similar to the Webber's Creek Series, are found associated with the Carboniferous rocks, south of the line of junction of that series with the other series.

The Webber's Creek Series seems to be of the same age as similar rocks near Clarencetown, which Jaquet* has determined as Upper Carboniferous. The throw of the Webber's Creek fault is about equal to the amount of strata between these rocks and the top of the Carboniferous strata, but, as the exact position of these rocks in the Upper Carboniferous has not been determined, it is not possible, at present, to say what is the amount of the throw of this fault.

* *Op. cit.*, p. 62.

*Summary.*—Representatives of two Systems—Carboniferous and Permo-Carboniferous—occur in the district described. The Carboniferous rocks all belong to the Upper Carboniferous, some being of the same age as the Clarencetown tuffaceous sandstones, etc., and others of the same series as the rhyolites, etc., at Mount Bright, near Pokolbin. The boundary between the two Carboniferous series is formed by an extensive E.-W. fault (the Webber's Creek fault), throwing to the south.

The Permo-Carboniferous rocks occur in two separate areas. Just north-east of Mount Tangorin, there is a small, triangular-shaped basin made up of representatives of the Lower Marine Series, Greta Coal-Measures and Upper Marine Series. The most important point, economically, here is the occurrence of the Greta Coal-Measures. Previously it was thought that this was just the southern end of an extensive occurrence of the Coal-Measures, but the discovery that it is a small isolated basin, shows that there is probably no Greta coal anywhere to the north-east of the district, and on the north-west, the next occurrence is somewhere not far south-east of Muswellbrook. The small extent of the Cranky Corner basin, and its inaccessible position, make it improbable that it will ever be of any considerable economic value. The other area of Permo-Carboniferous rocks is just west of Brook's Mountain. Here the Upper Coal-Measures are developed, enclosed on three sides by heavy faults. Upper Marine Series (Crinoidal Beds) occur farther to the west, on the western side of the Greta fault.

My thanks are due to many of the residents of the district, who were always willing to assist me as far as possible, and, in particular, to Mr Frank Drinan, of Glendon Brook, and Mr. J. Graham, of Westbrook. I also wish to express my gratitude to Professor David and Mr. W. S. Dun for the interest they have taken in my work, and for the help they have rendered me, in discussing and criticising this work in preparation.

## EXPLANATION OF PLATE XIV.

Geological Map of the Glendonbrook District.

[*From the Proceedings of the Linnean Society of New South Wales, 1913, Vol. xxxviii., Part 1, April 30th.*]

# STRATIGRAPHICAL GEOLOGY OF THE PERMO-CARBONIFEROUS SYSTEM IN THE MAITLAND-BRANXTON DISTRICT,

## WITH SOME NOTES ON THE PERMO-CARBONIFEROUS PALÆOGEOGRAPHY IN NEW SOUTH WALES.

BY A. B. WALKOM, B.SC., LINNEAN MACLEAY FELLOW OF THE SOCIETY IN GEOLOGY.

(Plates viii.-xiii., and ten text-figures.)

# STRATIGRAPHICAL GEOLOGY OF THE PERMO-CARBONIFEROUS SYSTEM IN THE MAITLAND-BRANXTON DISTRICT,

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(Plates viii.-xiii., and ten text-figures.)

This paper is the result of about four months' fieldwork in the Hunter River District, the area examined during that period being bounded on the north by the Hunter River, and on the other three sides roughly by a line drawn through West Maitland, Mt. Vincent, Mt. View, and Belford, and also a small area north of the Hunter River, between West Maitland and Paterson.

The most important work done on this area is Professor David's memoir on "The Geology of the Hunter River Coal-Measures of New South Wales."* In that work, the coal-measures are worked out in detail, but the Lower Marine Series and the Upper Marine Series are not treated in as great detail as the coal-bearing series. It was with the object of obtaining a more detailed knowledge of these two marine series, that this work was done. One portion of the outcrop of the Greta Coal-Measures, namely, that extending south from Branxton, was not very well-known at the time Pro-

* Mem. Geol. Survey N. S. Wales, Geology No.4, 1907.

fessor David's work was published; but since then, a good deal of prospecting has been done along this part of the outcrop, and fresh information was obtainable, and is included in this paper.

To make the lists of fossils as complete as possible, fairly large collections were made, and these have been supplemented by records of localities of fossils, from the publications of the Geological Survey of New South Wales, and from the "Catalogue of Australian Fossils," by R. Etheridge, Jr. In many cases, however, the record of the locality of fossils is not definite enough to permit of their horizon being determined. Only cases where the locality is sufficiently definitely stated, have been used in completing these lists. The map which accompanies the paper (Plate ix.) is part of Professor David's Map of the Hunter River Coal-Measures, published by the Geological Survey of New South Wales, in 1907, with additions which have resulted from my field-work.

## Lower Marine Series.

The development of the Lower Marine Series varies considerably in different parts of the district; vertical sections have been obtained in three places, and are shown in Figs. 1-3. In Fig. 1 (p. 116), which gives the most typical section, and that in which the series is most completely represented, the series attains a thickness of nearly 4,800 feet. This section is taken from the occurrences in the area between Farley, Greta, and Cessnock. Fig. 2 (p. 117) gives the succession near the Carboniferous inlier of Mt. Bright, where there is a considerable overlap of the lower beds. Fig. 3 (p. 118) is taken along the Elah Road, where there is also a considerable overlap.

The group of hills about one mile south-east of Lochinvar Township, of which Winder's Hill is the most prominent, is composed of a varied series of rocks of Carboniferous age. They include a variety of volcanic rocks, both acid and intermediate; and also sedimentary rocks, such as conglomerate, sandstone, and yellowish cherty tuff. These sedimentary rocks, in places, contain abundant plant-remains, such as *Rhacopteris*, which indicate that they are of Upper Carboniferous age.

Skirting the southern end of these Carboniferous rocks are the lowest beds of the Permo-Carboniferous System that occur in the Hunter River District, namely, the Lochinvar glacial beds. These can be traced, almost continuously, from a point just west of the village of Gosforth round to a point about half a mile south of the Hunter River, on the road from Lochinvar to Windermere, a total

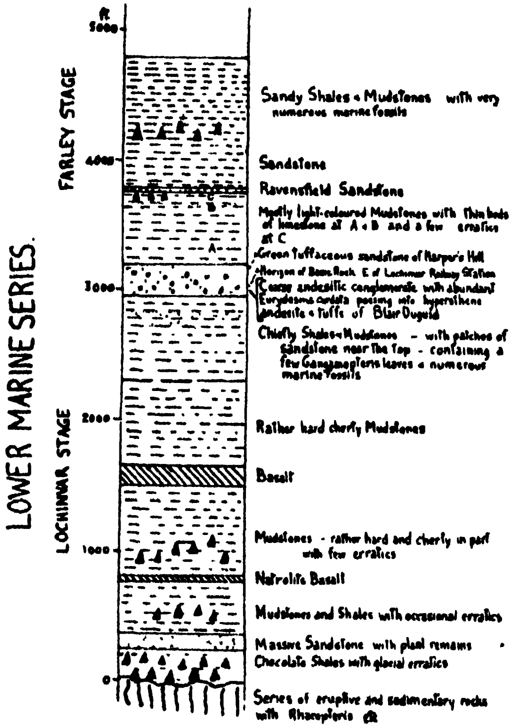


Fig. 1.—Vertical Section of Lower Marine Series in the Farley-Greta District.

distance of about five miles. In places, they are distinctly unconformable with the underlying beds. In portions 5 and 6, Parish of Gosforth, the Carboniferous rocks strike 225°, and dip to the south-east at high angles (58°-64°); and the strike of the glacial

beds varies between 195° and 170°, and they dip at low angles (15° to 8°). They have been described by Professor David,* and consist of fine-grained, reddish-brown to chocolate-coloured shales, containing numerous boulders up to about 2 feet in diameter. Very many of these boulders are waterworn, but some are undoubtedly striated and faceted as a result of ice-action. Their thickness varies, a section near the north-west corner of portion 13, Parish of Gosforth, gives their thickness as about 150 feet, but further south, on Windella Estate, they are quite 250 feet thick. There is a good outcrop on the road from Lochinvar to Windermere, but the lower limit there is hidden under recent alluvial, so that the thickness is not determinable. No marine fossils have ever been found in these shales. The glacial beds are not found on the northern side of the Hunter River. At the eastern end of the Carboniferous rocks, near Eelah, they are overlapped by higher members of the Lower Marine Series; while, at the western end of the Carboniferous complex, the Eldersleе fault has thrown the Upper Coal-Measures down against the Carboniferous.

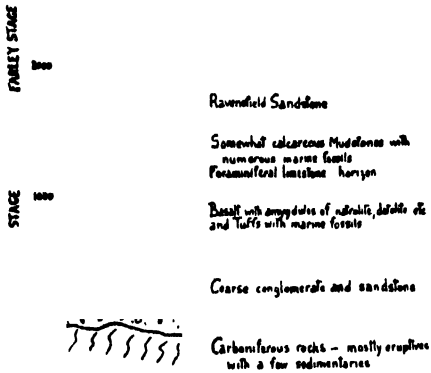


Fig. 2.—Vertical Section in the vicinity of Pokolbin and Mt. View.

Immediately overlying the chocolate shales, is a massive sandstone, about 100 feet thick, and no marine fossils have yet been reported from this. Careful search was made, at several points, in this sandstone for marine fossils, but without success. It contains, however, numerous plant-remains. There is a possibility, then, that this lowest part of the Lower Marine Series is of freshwater

* Journ. Proc. Royal Soc. N. S. Wales, 1899, xxxiii., pp. 154-159.

origin. As a new and extensive occurrence of the glacial beds has recently been described from the Kempsey District,* it would perhaps be as well to leave any further discussion of them until that area has been more fully worked out.

This stage is followed by an enormous development of marine sandstones and mudstones, with which are associated a number of contemporaneous lava-flows. There are, first, about 400 feet of gritty, ferruginous mudstone, followed by a flow of basalt, 50 feet thick, in which numerous small steamholes have become filled with secondary minerals, such as analcite, natrolite, calcite, etc.

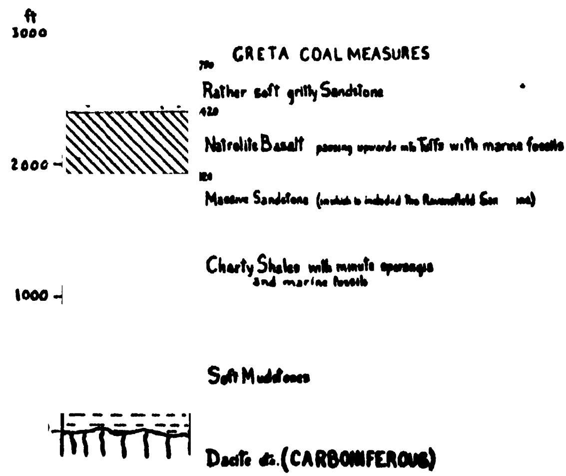


Fig. 3.—Vertical Section obtained along Eelah Road.

Then come 700 feet of rather hard shales and mudstones, which contain a few erratics, followed by a basalt-flow, 150 feet thick. This is followed by 1,300 feet of shales and mudstones, which also contain a few erratics, and near the top of which, there are numerous small patches of calcareous sandstone. About 100 feet above the basalt, the shales are somewhat cherty, and contain veins filled with a red secondary material, probably chalcedony.

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* W. G. Woolnough, Journ. Proc. Royal Soc. N. S. Wales, 1911, xlv, pp. 159-168.

It is in these beds that the lowest horizon for marine fossils in the series is found. About halfway up the series, and about 2,000 feet from the base of the marine series,* there is a zone in which *Ptycomphalina trifilata, P. nuda,* and *Gangamopteris* are found, the first-named being particularly abundant. This zone is exposed in a small quarry on the road, about half a mile north of Lochinvar Railway Station.

A little higher up in the mudstones, fossils become much more abundant, and the following have been found:—

| | |
|---|---|
| *Tribrachiocrinus* sp | *Merismopteria*, sp.nov. |
| Indeterminate crinoid. | *Aviculopecten sprenti.* |
| Crinoid stems. | *A. tenuicollis.* |
| *Fenestella*(?) *internata.* | *A. englehardti.* |
| *F.*(?) *fossula.* | *A.* sp. |
| *Stenopora tasmaniensis.* | *Deltopecten subquinquelineatus.* |
| *Spirifer duodecimcostata.* | *D. farleyensis.* |
| *S. stokesi.* | *Mæonia* sp. |
| *S. avicula.* | *Pleurophorus.* |
| *Martiniopsis subradiata.* | *Notomya*(?). |
| var. *morrisii.* | *Pachydomus.* |
| cf. *morrisii.* | *Mourlonia.* |
| *Productus cora* var. *farleyensis.* | *Ptycomphalina trifilata.* |
| *Strophalosia jukesi.* | *Platyschisma.* |
| *Chonetes* sp. | *Conularia.* |
| *Edmondia*(?) *nobilissima.* | |

In the sandstone patches, near the top of these mudstones, fossils are abundant, and comprise the following:—

| | |
|---|---|
| *Spirifer vespertilio.* | *Pleurophorus* sp. |
| *S. tasmaniensis.* | *Pachydomus.* |
| *Martiniopsis subradiata.* | *Mourlonia rotundatum.* |
| *Chænomya* sp. | *Keeneia* (juv.). |

* On p.322 of Professor David's Memoir, this is stated as 3,000 feet; it is probably a misprint, as on the vertical section accompanying that work, it is shown as about 2,000 feet.

| | |
|---|---|
| *Edmondia*(?) *nobilissima.* | *Conularia lævigata.* |
| *Deltopecten subquinquelineatus.* | Plant-stems. |
| *Mæonia*, 3 spp. | |

One hundred and fifty feet below the top of these mudstones, (or 2,450 feet above the base of the marine beds), in a band of dark-coloured, sandy, calcareous mudstone, numerous specimens of the pseudomorph Glendonite were obtained. Further details of this are embodied in a separate note.

Following the mudstones, there is a development of a coarse conglomerate with large waterworn pebbles, chiefly composed of andesite, followed by a rather soft gritty sandstone, and then a rather coarse, greenish, tuffaceous sandstone. These together form a thickness of strata of about 250 feet. The conglomerate is known as the Allandale Conglomerate, and contains an abundance of large molluscs with thick shells, such as *Eurydesma cordata, Platyschisma oculus, Keeneia platyschismoides,* etc. The greenish, tuffaceous sandstone is the Harper's Hill Sandstone. These beds are only developed locally in the neighbourhood of Allandale. Towards the south-east, they seem to give place to a development of tuffs associated with the hypersthene-andesite of Blair Duguid Hill. This hypersthene-andesite mass is contemporaneous in the Lower Marine Series; the mudstones can be seen dipping under it at a gentle angle ($9\frac{1}{2}°$-$10°$) on its northern side, and they have practically the same dip at its western end, so that they, apparently, have not been disturbed by the volcanic rock. The centre of eruption must have been somewhere in the vicinity of Blair Duguid Hill, and the activity here was doubtless responsible for some of the blocks of andesite in the Allandale Conglomerate, as well as for the tuffaceous nature of the Harper's Hill Sandstone. The hypersthene-andesite contains a great number of steamholes filled with secondary material, and beautiful specimens of agate, chalcedony, etc., can be obtained. At the eastern end of the mass, near the junction of two creeks in portion 152, Parish of Allandale, masses of chert, up to about 18 inches in diameter, have been floated up in the lava. This chert resembles very much that in which Carboniferous fossils are found near Winder's Hill, and

has probably been brought up from some considerable depth, as there would be nearly 3,000 feet of Permo-Carboniferous strata between this horizon and the underlying Carboniferous rocks.

Some distance to the east of Lochinvar Railway Station, there is a large mass of basic rock, which is on a horizon about 2,700 feet above the base of the marine beds; this, then, probably belongs to the same series as the volcanic rocks round Blair Duguid. In the opposite direction, to the north-west, the conglomerate seems to die out quickly, and give place to a thicker development of the Harper's Hill Sandstone, for there is no outcrop of the conglomerate on the main road to Singleton, going up Harper's Hill. Fossils are very numerous in these beds; in the railway-cutting, just over half a mile east of Allandale, there is a bed about 2 to 3 feet thick, composed mostly of the remains of thick shells like *Eurydesma cordata* and *Platyschisma*. The following is a list of fossils from these beds:—

Crinoid stems.
*Stenopora tasmaniensis.*
*S.* aff. *tasmaniensis.*
*S. ovata.*
*Fenestella*(?) *fossula.*
*Polypora.*
*Dielasma hastata.*
*D. sacculus.*
*Martiniopsis subradiata.*
  var. *morrisii.*
  cf. *morrisii.*
*Spirifer vespertilio.*
*S. stokesi.*
*S. tasmaniensis.*
*S. clarkei.*
*S.* sp.ind.
*Solenopsis* sp.
*Chænomya etheridgei.*
*C.* sp.
*Allorisma curvatum.*
*Aviculopecten tenuicollis.*
*A. squamuliferus.*
*A. mitchelli.*
*A. sprenti.*
*A.* sp.ind.
*Deltopecten illawarrensis.*
*D. fittoni.*
*D. limæformis.*
*Eurydesma cordata.*
*Aphanaia* sp.ind.
*Modiola crassissima.*
*Pleurophorus* sp.ind.
*Orthonota* sp.
*Notomya* sp.
*N. cuneata.*
*Pachydomus antiquatus.*
*P. lævis.*
*P. ovalis.*
*Orthonychia altum.*
*Platyceras*, n sp.

| | |
|---|---|
| *Edmondia*(?) *nobilissima.* | *Ptycomphalina trifilata.* |
| *Palæarca subarguta.* | *P. morrissiana*(?). |
| *Merismopteria macroptera.* | *Keeneia platyschismoides.* |
| *M.* n.sp. | *Platyschisma oculus.* |
| *M.* sp.ind. | *P. depressa.* |
| *Avicula intumescens.* | *Conularia inornata.* |
| | *C. lævigata.* |

Following the Harper's Hill beds, there are 560 feet of light-coloured mudstones, with two horizons of limestone-bands. The mudstones are somewhat calcareous, but, in the outcrops from which this section was obtained, they contain few fossils. Further south, however, near Pokolbin, there are numerous fossils in them (see later p.125). At about 130 feet above the base of the mudstones, there occur in several localities (marked $\alpha$ on the map) limestone-bands containing marine fossils, amongst which Fenestellidæ are abundant. The following fossils occur on this horizon :—

| | |
|---|---|
| *Stenopora.* | *Aviculopecten squamuliferus.* |
| *Fenestella*(?) *fossula.* | *Platyschisma.* |
| *F.*(?) *internata.* | *Euomphalus*(?). |
| *Spirifer.* | *Ptycomphalina.* |

In the cuttings, along the road from Allandale Railway Station to the main northern road, a number of small faults can be seen, which, however, cannot be traced on the surface. They appear to be a series of step-faults, with small throws to the north-east.

At 420 feet from the base of the same mudstones, there is another series of limestone-concretions at several places (marked $\beta$ on the map), but these contain only very few fossils.

Almost at the top of these beds, just below the Ravensfield Sandstone, in portions 46 and 47, Parish of Heddon, there are a number of large granitic erratics.

The mudstones are the topmost beds of the Lochinvar Stage, and are followed by the Ravensfield Sandstone, the lowest beds of the Farley Stage

The Farley Stage commences with the well-known Ravensfield Sandstone. This sandstone forms a very persistent horizon, and is from 12-20 feet thick. In the vicinity of Farley Railway Station, there is a considerable development of massive sandstone, reaching perhaps 200 feet in thickness, part of which is the Ravensfield Sandstone. The part which corresponds to the Ravensfield Sandstone, and which has been quarried for building-stone, is about the middle of this massive sandstone. It is difficult, however, to make a division-line in this sandstone, and the whole of it has here been included with the Farley Stage. A similar occurrence is met with on the Eelah Road, and will be described later(p.126). There are numerous conglomerate patches in the Ravensfield Sandstone, and they contain a varied and abundant marine fauna, amongst which are the following :—

*Lasiocladia.*
*Palæaster clarkei*
*P. stutchburii.*
*P. giganteus.*
*Fenestella*(?) *fossula.*
*F.*(?) sp.
*Dielasma cymbæformis.*
*D. biundata.*
*D.* sp.
*Spirifer tasmaniensis.*
*S. duodecimcostata.*
*S.* sp.
*Cyrtina*(?).
*Martiniopsis subradiata.*
    var. *morrisii.*
*Solenopsis* sp.
*Cardiomorpha*(?).
*Chænomya mitchelli.*
*C. etheridgei.*
*C.* n.sp.
*Edmondia*(?) *nobilissima.*
*Aviculopecten squamuliferus.*
*A. profundus.*
*Aviculopecten tenuicollis.*
*A. sprenti.*
*A. mitchelli*(juv.).
*Deltopecten limæformis.*
*D. subquinquelineatus*
*D. farleyensis.*
*D. fittoni.*
*Eurydesma cordata.*
    var. *ovale.*
*Mæonia carinata.*
*Pleurophorus.*
*Pachydomus.*
*Astartila corpulenta.*
Lamellibranch (new genus).
*Platyceras altum.*
*Platyschisma.*
*Ptychomphalina trifilata.*
*Conularia tenuistriata.*
*C. inornata.*
*Hyolithes lanceolatus.*
*Goniatites micromphalus.*
*Orthoceras*, 2 spp.

Perhaps the best outcrop of this is to be seen at Browne's Ravensfield Quarry, about three miles south-west from Farley Railway Station, where good collections can be obtained.

These sandstones are followed by a series of sandy shales and mudstones, and the whole stage attains a thickness of from 800 to 1,000 feet. The mudstones are, in general, light-coloured, but some bands are much impregnated with iron, and have become stained quite red. Fossils are very numerous, and good collections can be obtained from both the road and railway-cuttings near Farley Railway Station. The following is a list of fossils from the Farley beds:—

*Dielasma sacculus.*
*D. cymbæformis.*
*D. biundata.*
*D. amygdala.*
*D. inversa.*
*D. hastata.*
*Spirifer duodecimcostata.*
*S. stokesi.*
*S. tasmaniensis.*
*Martiniopsis subradiata.*
var. *morrisii.*
var. *konincki.*
*Productus cora* var. *farleyensis.*
*P. fragilis.*
*Rhynchonella.*
*Chonetes.*
*Cardiomorpha gryphioides.*
*Edmondia*(?) *nobilissima.*
*Aviculopecten squamuliferus.*
*A. tenuicollis.*
*A. sprenti.*
*A. englehardti.*
*Aphanaia* sp.
*Mytilus bigsbyi.*
*Modiolopsis.*
*Mœonia.*
*Pleurophorus* sp.
*P. gregarius.*
*Stutchburia farleyensis.*
*Pachydomus.*
*Platyschisma oculus.*
*P. rotundatum.*
*Conularia inornata.*
*Goniatites micromphalus.*

In the upper 200 feet of these beds, *Nuculana waterhousei*, which does not appear in the lower part, is of fairly frequent occurrence.

An interesting and somewhat different vertical section is obtained in the vicinity of Pokolbin and Mt. View (Fig.2). More than 2,000 feet of the Lochinvar Stage have been overlapped in this part. The lowest member of the stage here is a coarse conglomerate and sandstone, at least 600 feet thick, which

is on about the same horizon as the Harper's Hill beds further north. Their thickness is rather difficult to estimate at all accurately on account of some doubtful faulting which occurs just north-east of Mt. View, but it is quite 600 feet, possibly more. This conglomerate was evidently deposited close to the old Carboniferous islands, the rocks of which have been described elsewhere.* The conglomerate is here followed by a development of basalt and tuffs, attaining a thickness of about 440 feet. The basalt contains numerous steamholes filled with such minerals as natrolite, datolite,† analcite, etc. The tuffs overlie the basalt, for the most part, and contain marine fossils. The position of the centre from which these basalts and tuffs were poured out, is doubtful. A couple of small patches of olivine basalt have been observed, quite isolated and in the midst of the acid volcanic rocks of the Carboniferous inlier of Mt. Bright. The most reasonable explanation of these occurrences seems to be, that they are old volcanic necks, and they may represent the old pipes from which this series was erupted. The tuffs are followed by 650 feet of calcareous mudstones One hundred and fifty feet above the base of these mudstones, there is a well-marked development of limestone containing numerous well-preserved Foraminifera, which have been described by Messrs. Chapman and Howchin.‡

This bed of limestone is on the same horizon as those mentioned above(p.122). Ostracods are found in these beds, as well as numerous marine fossils, *e.g.*

| | |
|---|---|
| Crinoid stems. | *Aviculopecten tenuicollis.* |
| *Stenopora tasmaniensis.* | *A. sprenti.* |
| *Fenestella*(?), 2 or 3 species. | *A. squamuliferus.* |
| *Protoretepora.* | *elto pecten farleyensis.* |
| *Spirifer tasmaniensis.* | *Mœonia carinata.* |
| *S. duodecimcostata* | *Pachydomus*, 3 or 4 species. |
| *Martiniopsis subradiata.* | *Ptycomphalina*(?). |
| *Aviculopecten mitchelli.* | |

* Journ. Proc. Royal Soc. N. S. Wales, 1911, xlv., pp.379-408.
† C. Anderson, Rec. Austr. Museum, 1904, v., pp.127-130.
‡ Mem. Geol. Survey N. S. Wales Palæontology, No.14, 1905.

The other section of the Lower Marine Series to be described, is that obtained along the Eelah Road(Fig.3). Here, resting directly on Carboniferous rocks, there is a large development of mudstones and cherty shales. These attain a thickness of about 1,570 feet, and there has been an overlapping of more than 2,000 feet of strata below them. The mudstones are in the lower portion, and have been more easily eroded than the cherts, and so the former show few outcrops. The cherty shales, however, give good outcrops, and, near the top, a few marine fossils have been found. These include

| | |
|---|---|
| Crinoid stems. | *Eurydesma cordata.* |
| *Spirifer tasmaniensis.* | *Pachydomus.* |
| *S. vespertilio.* | *Platyschisma.* |

These shales are followed by about 350 feet of massive sandstone. This contains the equivalent of the Ravensfield Sandstone, which has been quarried extensively at Comerford's Quarry. This thick development of sandstones is similar to that mentioned near Farley Railway Station, and, as in that case, it has been included with the Farley Stage.

Above the sandstone, there is a thick series of basalt and tuffs. The basalt contains steamholes which have become filled with secondary minerals, such as calcite, natrolite, etc. The tuffs contain numerous fossils, amongst which are

| | |
|---|---|
| *Fenestella*(?) *fossula.* | *Aviculopecten mitchelli.* |
| *Stenopora.* | *A. tenuicollis.* |
| *Spirifer tasmaniensis.* | *Mæonia carinata.* |
| *Martiniopsis subradiata.* | *Platyschisma oculus.* |
| *Eurydesma cordata.* | |

In the areas previously described, the development of basalt and tuffs has been confined to the Lochinvar Stage, but here there seems to be no doubt but that the volcanic activity took place during the deposition of the rocks of the Farley Stage. This area must have been close to the shoreline at this time, as indicated, by the abundance, in the tuffs, of thick-shelled molluscs, which inhabit shallow, turbulent waters. These tuffs

are overlain by a series of a little over 300 feet of brownish sandstones, which are followed by the Greta Coal-Measures.

## THE GRETA COAL-MEASURES.

Professor David mapped the outcrop of these Measures, and gave numerous detailed sections of the coal-seams developed at many points along the outcrop. At the time of publication of his work,* however, very little information was obtainable about the development between Branxton and Pokolbin.† Since that time, a new colliery (the Rothbury Colliery) has been opened, and the coal prospected at three other points along the outcrop on Rothbury Estate. To the manager of this colliery, Mr. Richard Thomas, Jr., I am indebted for most of the information contained in this section. The four separate points at which sections of the seams have been measured are:

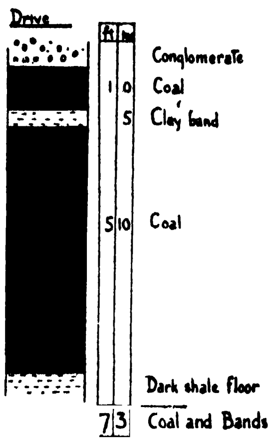



Fig 4 Section of Upper Seam at Rothbury Collieries

(1.) Rothbury Colliery (on portion 26, Parish of Branxton).

(2.) Where the outcrop crosses Black Creek.

(3.) In portion 17, Parish of Rothbury.

(4.) Where the outcrop crosses Rothbury Creek.

(1.) Rothbury Colliery.—As seen from Plate viii., the most complete section has been obtained at this point. Underneath a solid conglomerate-roof, there is a 7 feet 3 inches seam (see Fig.4).

* Mem. Geol. Survey N. S. Wales, Geology, No.4, 1907.

† *Op. cit.*, pp.138-140.

Exposure to the atmosphere gives a yellowish tinge to the surface of the coal from this seam, and a small amount of sulphur is deposited in the cracks. Although no crystalline pyrites has been observed, there is probably a small percentage of it in the coal; and this sulphur has been set free during the oxidation of the pyrites to iron sulphate ($FeSO_4$). This seam has a floor of dark shale, and then, for a thickness of about 60 feet, the strata are chiefly sandstones and a massive conglomerate. Then follows the best seam of this locality. Within a very short distance (only a few yards) of the outcrop, the seam is 12 feet 6 inches thick; and, at 170 yards in, along the tunnel, the seam has thickened to 14 feet $4\frac{1}{2}$ inches, including bands (see Fig.5).

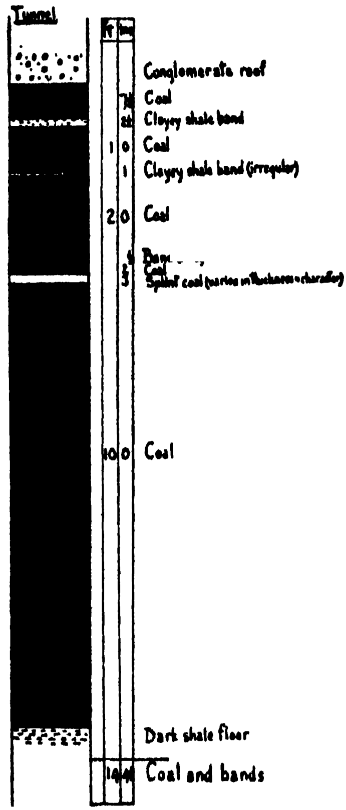



Fig 5 . Section of coal seam at Rothbury Collieries

The lower ten feet of this seam is being worked at the Rothbury Colliery. The seam dips N.55°W. at $18\frac{1}{2}°$, and consists of hard, semibituminous coal.

*Analyses of some Coals from the Lower Split of the Main Greta Seam.*

| | i. | ii. | iii. | iv. | v. | vi. |
|---|---|---|---|---|---|---|
| Hygroscopic moisture ... ... | 2·35 | 1·87 | 1·54 | 2·38 | 2·10 | 1·58 |
| Volatile hydrocarbons ... ... | 40·74 | 40·63 | 42 05 | 41·01 | 41·45 | 42·72 |
| Fixed carbon ... .. ... | 51·11 | 50·52 | 49·29 | 51·70 | 49·74 | 50·30 |
| Ash... ... ... ... ... | 5·80 | 6·98 | 7·12 | 4·91 | 6·71 | 5·40 |
| Sulphur ... ... ... ... | 0·694 | 0·766 | 0·862 | 1·159 | 0·947 | 0 873 |
| Sp.Gr. ... ... ... ... | 1·290 | 1·303 | 1·304 | 1·282 | 1·251 | 1·272 |
| Coke ... ... ... ... | 56·91 | 57·50 | 56·41 | 56·61 | 56·45 | 55·70 |
| Lbs. of $H_2O$ converted to steam by 1lb. coal ... ... ... | 13·5 | 13·5 | 12·9 | 13·3 | 13·0 | 13·5 |

i. Rothbury Collleries* (No.1 sample). Coke fairly swollen, firm and lustrous. Ash, grey in colour; semigranular.

ii. Rothbury Collleries* (No.2 sample). Coke fairly swollen, firm and lustrous. Ash grey; semigranular.

iii. Ebbw Main, Greta.† Bands picked out; coke fairly swollen, firm and lustrous. Ash buff-coloured; semigranular.

iv. Stanford Merthyr.‡ Coke slightly swollen, firm and lustrous. Ash buff-coloured; semigranular.

v. Pelaw Main.§ Coke well swollen, firm and lustrous. Ash light reddish tinge; semigranular.

vi. Hebburn.|| Coke fairly swollen, firm and lustrous. Ash pink; semigranular.

The above table gives analyses of two samples of coal from the Rothbury Collieries; and analyses, for comparison, from the same seam in four other collieries. The Rothbury coal is very suitable for gasmaking and steaming, and also makes a good coal for household purposes. It gives only a small percentage of small coal, and is a good coal for shipment, as it stands handling well.

This seam has a floor of dark shale, and the sandstone and conglomerate have been proved for about 20 to 24 feet below. Then there is a gap of approximately 20 feet, in which the strata

* Analyses kindly supplied by Mr. Richard Thomas, Jr., Manager.

† E. F. Pittman, "The Coal Resources of New South Wales." Geological Survey of N. S. Wales, 1912, p.68.

‡ *Idem*, p.75. § *Idem*, p.73. || *Idem*, p.69.

have not been touched by prospecting shafts, but there is little doubt that this portion is composed of sandstone and conglomerate. Below this, the section is given in a shaft some 185 feet east of the main tunnel mouth. The section of this shaft is(Fig.6):

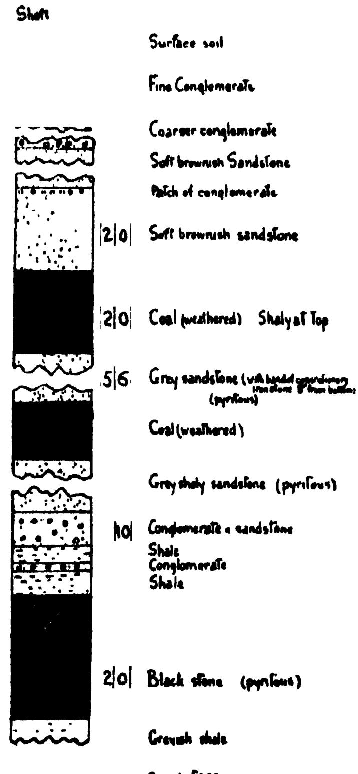


Fig 6 Section of Bottom Seams at Rothbury Colliery

It shows a couple of weathered seams of coal, and a band of about one foot of kerosene-shale. In this lower part of the section, there is a sprinkling of small crystals of pyrites through the shale and sandstone, and also through the two feet of "Blackstone" at the bottom. The coal shown by the shaft is very weathered, and of no use; but it is, of course, possible that, further in from the outcrop, it may lose its weathered character. The greyish, shaly sandstone, between the seams, contains fairly abundant plant-remains, amongst which *Glossopteris* is the most prominent; some of the stems of these plants are replaced by pyrites.

(2.) Black Creek.—At Black Creek, about one mile south of the Rothbury Collieries, two seams can be seen, corresponding to the two upper ones at the first locality. The top one of these two seams has not been prospected, but a tunnel in the lower one revealed the following section(Fig.7, p.131).

It was near the position of this tunnel that Professor David had a shaft put down some years ago,* and obtained 9 feet, 9

* *Op. cit.*, p.139.

inches of coal and bands. The newer section gives a greater thickness of coal and bands (11 feet, 0½ inch), thus bearing out Professor David's opinion that the seam, being somewhat perished in his shaft, would probably be found to have a greater thickness.* There is a small band of white clay just below the top seam. The two seams at this point are about 40 feet apart, and their dip is N.47°W. at 24°.

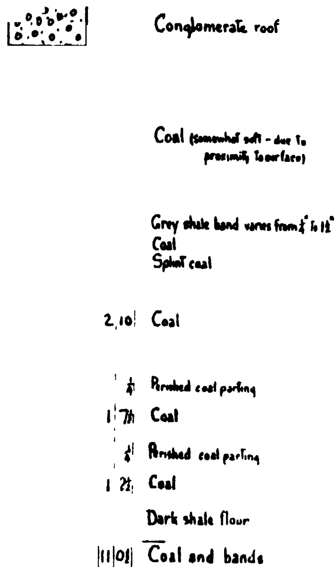



Fig 7 Section of Seam at Black Creek

(3.) Portion 17, Parish of Rothbury. – A small tunnel has been driven in portion 17, Parish of Rothbury, (about 1¾ miles south of the Black Creek tunnel), and a seam (with band) of 6 feet, 2 inches struck, giving the following section (Fig.8):—

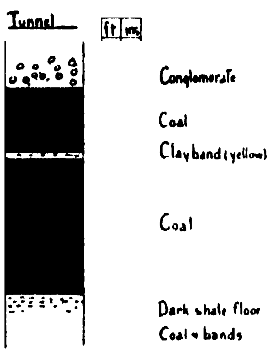


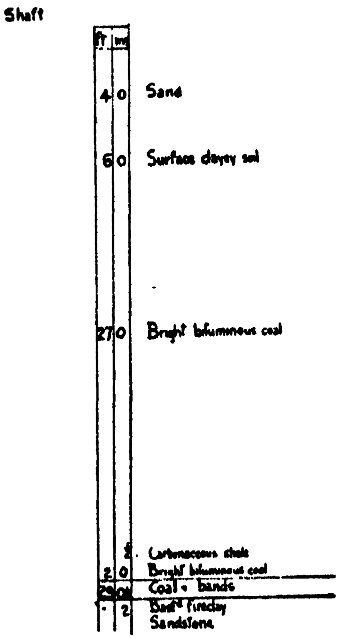

Fig 8 Section of Upper Seam on Portion 17 Par Rothbury

This seam is the equivalent of the top seam further north at the Rothbury Colliery. It does not quite attain the thickness of that seam, but, when exposed to the weather, the same yellow stain and sulphur-deposit are noted as at the Colliery. There is also a slight smell of $H_2S$ in

* *Op. cit.*, p.140.

this old tunnel. These phenomena denote the presence of a small amount of pyrites in the coal.

(4.) Rothbury Creek.—Three-quarters of a mile further south, the outcrop crosses the Rothbury Creek. Here Professor David noted the outcrop of a coal-seam in the creek.‡ When I visited the spot, the outcrop in the creek was under water, but a shaft has been sunk for 39 feet, on the bank a few yards away, of which the following is a section(Fig.9):—




True Thickness of Seam abt 21ft

Fig 9 Section of Seam on bank of Rothbury Ck

It will be noted that the top boundary of the seam is horizontal, instead of dipping parallel to the bottom-edge. This indicates that the seam has been eroded somewhat. That this is so, is further indicated by the fact that, in the creek, there is a solid conglomerate dipping conformably just above the seam; while, in the shaft, there is no trace of the solid conglomerate, but only surface-sand and clayey soil. The seam dips N.60° W. at 45°, and has a thickness of at least 21 feet, and as the surface has been somewhat eroded, the thickness is probably somewhat more. It is a bright, bituminous coal of good quality, and

‡ *Op. cit.*, p. 140.

apparently does not deteriorate readily on exposure, as the shaft had been made over two years at the time of my visit, and the coal, which had been lying about for that time, showed only a slight amount of surface-discolouration; and when broken open, was as bright and hard as coal freshly taken out. About 75 yards up the creek, there is an outcrop of another seam, but the water was too high for me to see it. However, Mr. R. Thomas, Jr., informed me that he had got specimens of coal *in situ* at that point, when the creek had been drier. At the point in the creek where this outcrop occurs, the boulders in the creek-bed are all coated black, and there is a very strong smell of $H_2S$.

Plate viii. is a series of comparative vertical sections of the various seams just described. On comparison with section No. x,* accompanying Professor David's Memoir, there seems little doubt but that the top seam, in each case, represents the upper split in the main Greta seam. This is further confirmed by the presence of pyrites, which is indicated in these seams. The lower split of the main Greta seam appears to have become further split between Rothbury Creek and Black Creek, and a bed of conglomerate and sandstone, some 60 feet thick, is developed between the two parts. The 14 feet, 4½ inches seam at the Rothbury Colliery, and the 11 feet, 0½ inch seam at Black Creek, represent the top part of this lower split; and the lowest seams at Rothbury Colliery represent minor splits of the bottom-part of the lower split. The 21 feet seam at Rothbury Creek probably represents the whole of the lower split of the main Greta seam.

### *Summary of Greta Coal-Measures in this district.*

The main Greta seam, or part of it, has been prospected in four places, and the seam is split as at other localities.

In each of the four localities, the upper split of the main Greta seam has been struck.

The lower split seems to be entire at Rothbury Creek, but splits further to the north.

* Section No. x is a comparative series of vertical sections of the Greta coal-seams.

The upper split contains a small amount of pyrites; in the top part of the lower split, no trace of this mineral has been observed; in the sandstone and "black-stone" associated with the bottom part of the lower split, there is a small percentage of pyrites.

The dips are in directions N.47°W. to N.60°W., and increase in amount as they get further south, *i.e.*, as they approach nearer to the eastern branch of the Eldersleе fault. The band of conglomerate, between the two splits, appears to thicken very considerably towards the south.

The amount of perishing of the seams near the surface does not appear to be so great here as in the eastern and southern portions of the Greta Coal-Measures outcrop.

## Upper Marine Series.

The Upper Marine Series, in the Hunter River District, occupies a much larger and more widely scattered area than the Lower Marine Series, and, for that reason, could not be studied in as much detail as the latter, in a comparatively short time. Examination of a number of the most typical exposures, however, enables one to form a fairly accurate estimate of the succession.

Whereas sedimentation in Lower Marine time was interrupted at frequent intervals by outbreaks of volcanic activity, in the Upper Marine of this district there were no such volcanic outbursts, and the sedimentation was uninterrupted. It must be remembered, however, that this is not true for other areas of Upper Marine sedimentation, *e.g.* in the South Coast District, there is abundant evidence of volcanic activity in Upper Marine time.*

The Upper Marine Series has been divided into three stages, namely, the Branxton, Muree, and Crinoidal Stages, by Professor David.†

---

*Jaquet, Card and Harper, Rec. Geol. Surv. N. S. Wales, 1905, viii., Pt. I.—Card and Jaquet, Rec. Geol. Surv. N. S. Wales, 1903, vii., Pt. 3.

† *Op. cit.*, p.319.

The lowest (Branxton) stage is from 3,000 to 3,200 feet thick, and follows immediately on the Greta Coal-Measures. This stage might be divided into two parts, (1) *lower*, with a thickness of about 1,400 feet; and (2) *upper*, 1,600 to 1,800 feet thick. The lower part consists of hard, massive, white to brown sandstone, often passing into conglomerate. In the lower 900 ft, the sandstone is often considerably iron-stained, and contains occasional bands of ironstone. At 900 feet from the base, there is a bed about 100 feet thick, of bluish-grey to brown mudstone, in which *Mytilus* and *Aphanaia* are common. Above this, there is a very hard, white sandstone, which forms a prominent outcrop near Black Creek, south of the railway line just west of Branxton. This particular bed is about 200 feet thick, and its outcrop is shown on the map. It contains a few marine fossils (e.g., *Spirifer*, *Martiniopsis*, and *Aviculopecten*), and numerous remains of plant-stems.

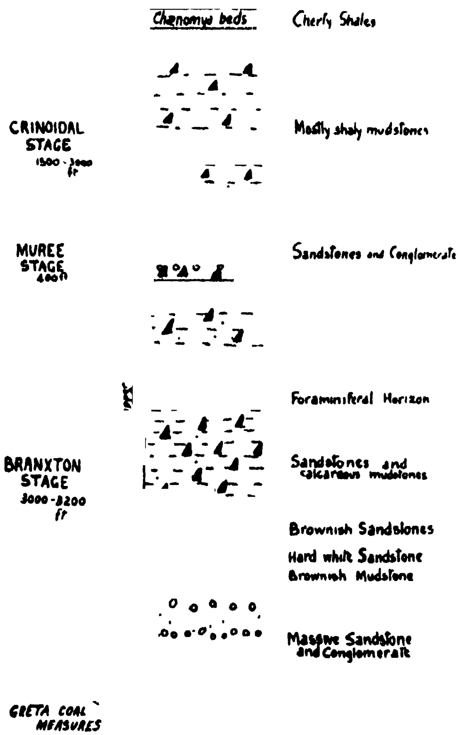



Fig. 10.—Vertical Section of the Upper Marine Series.

The remainder of this substage consists of more brownish sandstones. Marine fossils occur abundantly in this lower part of the Branxton Stage, and, where conditions were favourable,

they approach to within a few feet of the top seam of the Greta Coal-Measures. The following is a list of the fossils from this substage:—

| | |
|---|---|
| *Zaphrentis robusta.* | *Strophalosia jukesi.* |
| *Palæaster clarkei.* | *Chænomya etheridgei.* |
| *Protoretepora ampla.* | *C. undata.* |
| *Fenestella(?) fossula.* | *Aviculopecten englehardti.* |
| *Dielasma inversa.* | *A. ponderosus.* |
| *D. biundata.* | *A. tenuicollis.* |
| *D. hastata.* | *A.* sp. |
| *Spirifer convoluta.* | *Deltopecten farleyensis.* |
| *S. vespertilio.* | *D. leniusculus.* |
| *S. avicula.* | *D.* sp. (juv.). |
| *S. tasmaniensis.* | *Seminula(?).* |
| *S. duodecimcostata.* | *Mæonia carinata.* |
| *S. strzeleckii.* | *M. valida.* |
| *Martiniopsis oviformis.* | *Stutchburia costata.* |
| *M. subradiata.* | *Astartila polita.* |
| var. *transversa.* | *Leptodomus duplicicosta.* |
| var. *morrisii.* | *Platyschisma oculus.* |
| *Productus brachythærus.* | *Goniatites micromphalus.* |

The upper half of the Branxton Stage is composed of sandstones and calcareous mudstones, with frequent shaly bands. They contain numerous glacial erratics, which sometimes attain a very large size, some of them being over two tons in weight. These beds are exceedingly rich in marine fossils, perhaps the most abundant being members of the Fenestellidæ(?). In them, at about 2,300 feet from the base of the Branxton Stage, occurs a limestone-horizon which contains numerous well-preserved Foraminifera.* This upper part is also characterised by an abundance of *Trachypora wilkinsoni*, which is only found sparingly on any other horizon of the Upper Marine, and is extremely scarce in the Lower Marine. Good outcrops of the

* Chapman and Howchin, "Monograph of the Foraminifera of the Permo-Carboniferous limestones of N. S. Wales." Mem. Geol. Surv. N. S. Wales, Pal., No. 14, 1905.

Branxton Stage can be seen almost anywhere, where it is shown on the map. A good occurrence of glacial beds has been exposed by the new road-cutting on the Branxton to Elderslee road, just before it reaches the Elderslee Bridge over the Hunter River. The following is a list of the fossils from this upper part of the Branxton Stage :—

| | |
|---|---|
| *Zaphrentis robusta* | *Productus brachythærus.* |
| Crinoid stems. | *Strophalosia jukesi.* |
| *Trachypora wilkinsoni.* | *S. gerardi.* |
| *Stenopora.* | *S. clarkei.* |
| *Protoretepora ampla.* | *Chænomya etheridgei.* |
| *P. konincki.* | *Merismopteria.* |
| *Fenestella*(?) *internata.* | *Conocardium australe.* |
| *F. fossula.* | *Aviculopecten tenuicollis.* |
| *F. plicatula.* | *Deltopecten fittoni.* |
| *Spirifer convoluta.* | *D. leniusculus.* |
| *S. strzeleckii.* | *Aphanaia gigantea.* |
| *S. vespertilio.* | *Mæonia carinata.* |
| *S. stokesi.* | *Pleurophorus morrisii.* |
| *S. tasmaniensis.* | *Stutchburia costata.* |
| *S. duodecimcostata.* | *S. compressa.* |
| *S.* sp. | *Platyschisma rotundatum.* |
| *Martiniopsis oviformis.* | *Conularia.* |
| *M. subradiata.* | *Hyolithes lanceolatus.* |
| var. *konincki.* | *Goniatites micromphalus.* |

The upper limit of the Branxton Stage is well-defined by the Bolwarra Conglomerate ("Muree Rock"), which forms the base of the Muree Stage. This is a massive conglomerate, on which very little grass or vegetation of any kind will grow, and which forms a bold, bare outcrop, very useful indeed for purposes of geological mapping. This conglomerate passes upwards to a hard, massive, somewhat calcareous sandstone, and the whole Stage attains a thickness of about 400 feet. Both the conglomerate and the succeeding sandstone contain numerous marine fossils, there being a most remarkable abundance, in places, of the small

brachiopod, *Strophalosia*. The following is a list of fossils from the Muree Stage:—

*Zaphrentis phymatoides.*
*Phialocrinus princeps.*
*Archæocidaris.*
*Stenopora crinita.*
*Protoretepora.*
*Dielasma biundata.*
*D. amygdala.*
*D. cymbæformis.*
*D. hastata.*
*Productus brachythærus.*
*Spirifer convoluta.*
*S. clarkei.*
*Spirifer stutchburii.*
*S. duodecimcostata.*
*Martiniopsis cyrtiformis.*
*M. oviformis.*
*Strophalosia clarkei.*
*S. gerardi.*
*Conocardium australe.*
*Deltopecten leniusculus.*
*Mæonia fragilis.*
*M. carinata.*
*Entomis jonesi.*

One of the best exposures of this Stage is in the vicinity of Mt. Vincent, just east of Mr. Charles Wyndham's residence at Wollong, at the place known as "Bow Wow." Here the Muree Beds weather into large caves or rock-shelters, where numerous fossils can easily be obtained.

Above the Muree Stage comes the Crinoidal Stage. This varies very considerably in thickness in places, having a minimum of about 1,500 feet, and a maximum of from 3,000 to 4,000 feet. For the most part, it consists of fairly soft shales and mudstones. These weather fairly readily, and in this lies the reason for the development of some of the extensive alluvial flats, *e.g.*, along the course of the Mulbring or Wallis Creek. For the same reason, good outcrops are not of as frequent occurrence as they are in the more resistant beds. They can be seen outcropping, however, near Mt. Vincent, and in the railway-cuttings and creeks to the west and south of Belford. In places, they contain small and large erratics; *e.g.*, where the old line of northern road crosses a small creek in portion 61, Parish of Rothbury, there are numerous, small erratics of such rocks as aplite, quartz-porphyry, quartzite, and fine-grained, black, basaltic rocks. A little further east, where the same road crosses Jump Up Creek, there are a number of large erratics, an aplitic one reaching quite three feet in diameter, and one about the same size, of coarse granite,

containing grains up to nearly an inch long. These erratics are imbedded in brownish, calcareous mudstones, which also contain marine fossils. In this district, in the Crinoidal Shales there are two horizons, on which numerous specimens of the pseudomorph Glendonite occur, namely, (1) about 200 feet above the base (outcrop at Glendon), and (2) about 700 to 1,000 feet above the base (outcrops at Mt. Vincent and Singleton Railway Bridge). This stage terminates upwards in a series of hard, cherty shales, which have been quarried for road-metal, known as the Chænomya beds. These, as may be surmised from the name, contain large numbers of the fossil *Chænomya*; they also contain obscure casts of radiolaria. These Chænomya beds attain a thickness of 150 to 200 feet. The following is a list of fossils from the Crinoidal Stage:—

*Zaphrentis phymatoides.*
*Archæocidaris*, sp.ind.
*Tribrachiocrinus corrugatus.*
*Stenopora crinita.*
*Protoretepora.*
*Fenestella*(?).
*Spirifer convoluta.*
*S. duodecimcostata.*
*Martiniopsis subradiata.* var. *morrisii.*
*Strophalosia.*
*Chænomya etheridgei.*
*C. audax.*
*C. mitchelli.*
*C.* sp.
*Deltopecten fittoni.*
*Eurydesma hobartense.*
*Mæonia carinata.*
*Goniatites micromphalus.*

## Notes on the Permo-Carboniferous Palæogeography in New South Wales.

During almost a year's study of the Permo-Carboniferous rocks of Eastern Australia in general, and New South Wales in particular, some facts with regard to the palæogeography have become apparent, which are contrary to the ideas generally held. This is especially so with the distribution of land and sea in New South Wales. It has generally been held that, in Permo-Carboniferous time, New England and north-eastern New South Wales were cut off from the main continental mass, and that there was a water-connection with Queensland, to the west of New England. Professor David expressed this view recently in

his Presidential Address to the Royal Society of New South Wales, thus: "At this time [Permo-Carboniferous], Eastern Australia was probably, from New England to Townsville, isolated from the portion lying further to the west, first by the Permo-Carboniferous sea, and later by the lakes and swamps of that period."*

The following notes attempt to show the distribution of land and sea in New South Wales in Permo-Carboniferous time, as suggested by the results obtained by recent workers in the North-eastern portion of the State, particularly Mr. J. E. Carne, Professor Woolnough, and Mr. E. C. Andrews.

The ideas put forward are by no means to be regarded as final solutions of the problems, my chief reason for bringing them forward here being that they may serve as something tangible, to be modified as further information is brought to light. A very important area in connection with this subject, and one which is not well known at present, is that between the Manning and Clarence Rivers. When the various Palæozoic formations in this area have been determined and mapped correctly, it is probable that a number of modifications will have to be made in the maps presented here.

The results of recent work in Northern New England mostly show that the extensive series of shales and slates there, are of Permo-Carboniferous age,† and that the great granitic masses have intruded the Lower Marine rocks, and are thus of late Permo-Carboniferous or even Mesozoic age. These two results point to the fact, that the greater part of what is now northern New England, was under water in Lower Marine time. Other

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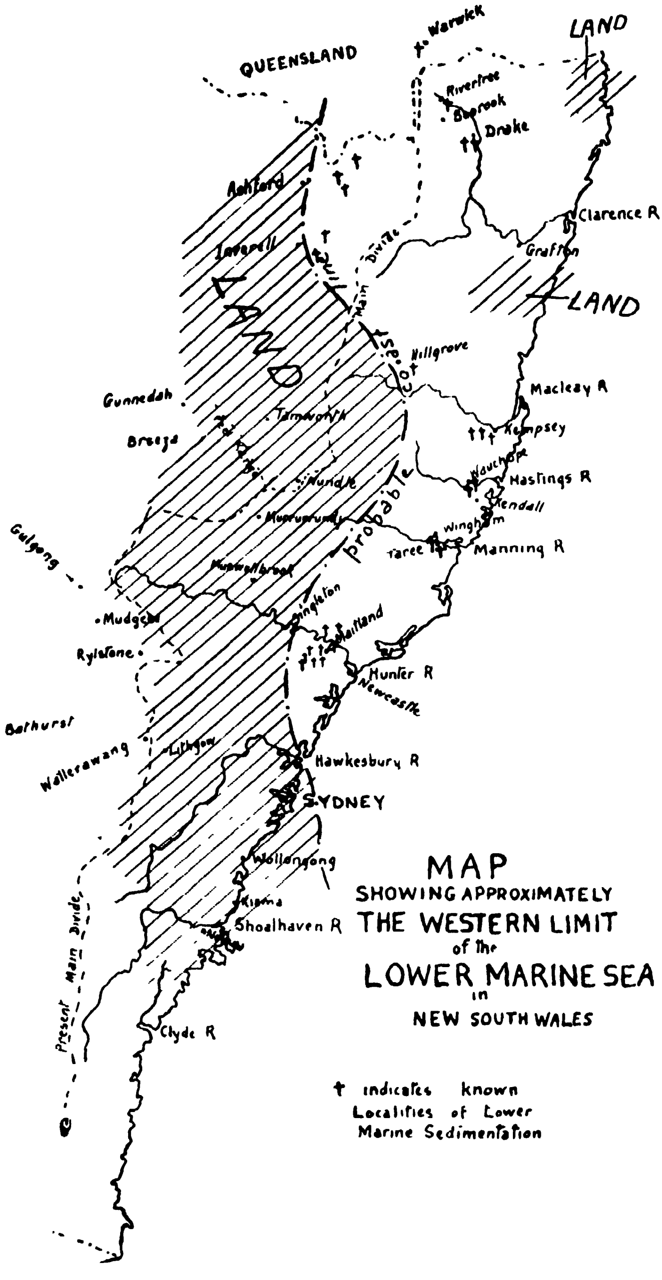
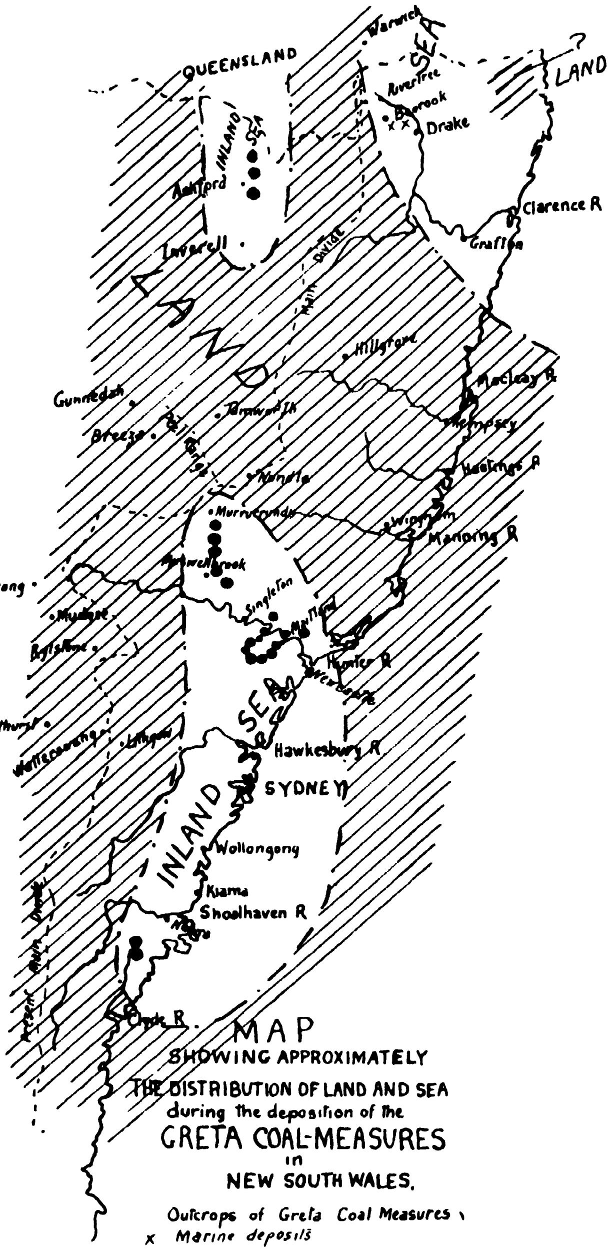
* Journ. Proc. Royal Soc. N. S. Wales, 1911, p.54.

† With regard to the slates in the neighbourhood of Tingha, two recent workers do not agree. Mr. L. A. Cotton[8] regards them as being older than Permo-Carboniferous, and similar to the Ordovician slates of Berridale and Tallong. Mr. J. E. Carne[7] puts them down as Permo-Carboniferous, evidently on account of their lithologic similarity to occurrences further north, in which he found Permo-Carboniferous fossils. Which of these views may be correct, however, does not affect these notes to any great extent, as it would only mean a small alteration in the position of the western limit of the Lower Marine Sea.




# MAP
SHOWING APPROXIMATELY
THE WESTERN LIMIT
of the
LOWER MARINE SEA
in
NEW SOUTH WALES

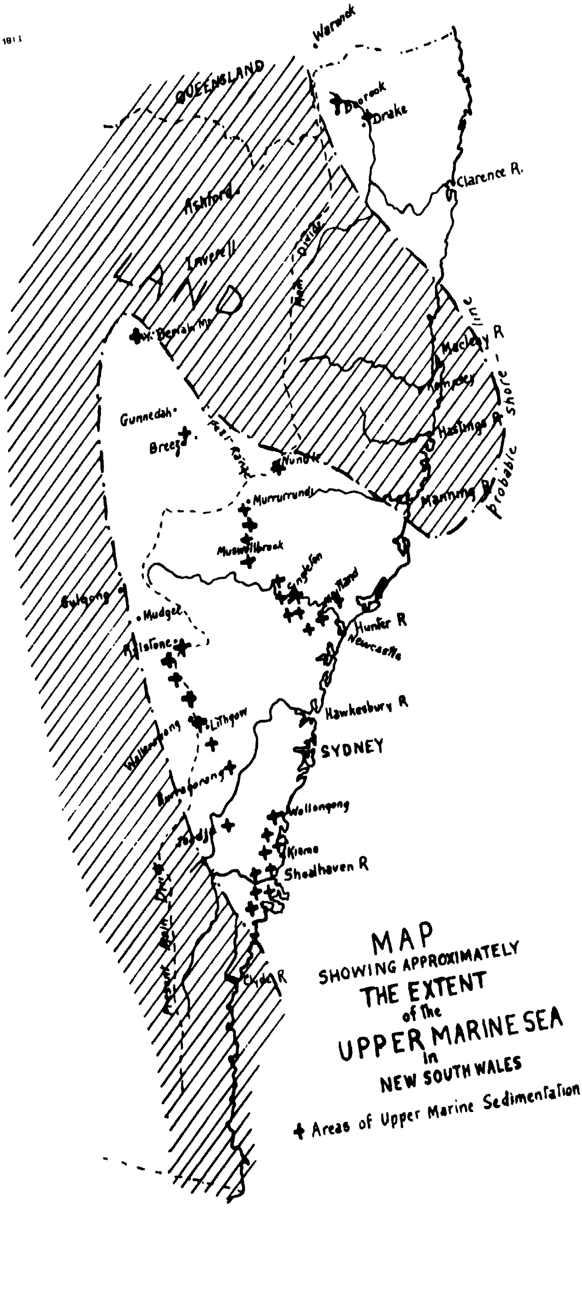
† indicates known Localities of Lower Marine Sedimentation

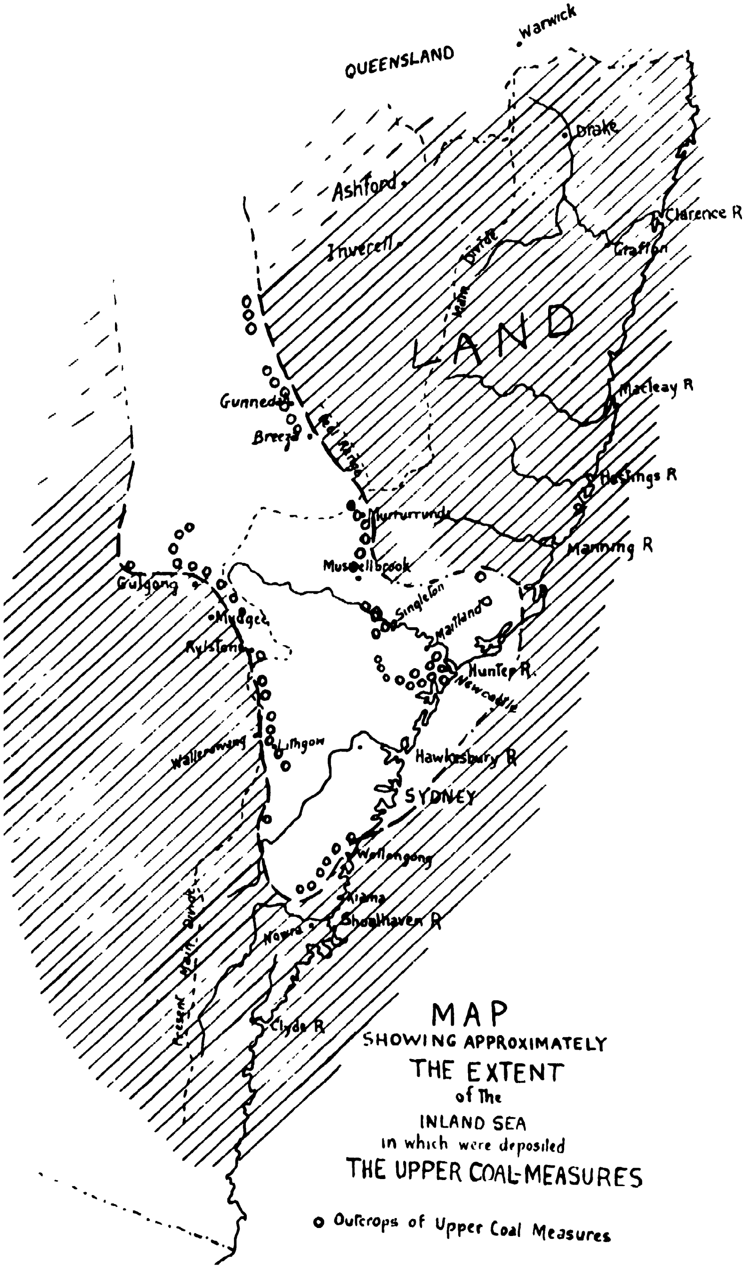



MAP
SHOWING APPROXIMATELY
THE DISTRIBUTION OF LAND AND SEA
during the deposition of the
GRETA COAL-MEASURES
in
NEW SOUTH WALES.

Outcrops of Greta Coal Measures
x Marine deposits

P. L. S. N. S. W. 1911


Warwick
QUEENSLAND
Deepwater
Drake
Clarence R.
Ashford
Inverell
LAND
Mt. Boorah
Divide
Gunnedah
Breeza
Nundle
Murrurundi
Muswellbrook
Singleton
Maitland
Hunter R
Newcastle
Mudgee
Macleay R
Hastings R
Manning R
Probable Shore line
Gulgong
Hawkesbury R
Lithgow
SYDNEY
Wollongong
Kiama
Shoalhaven R
Clyde R
MAP
SHOWING APPROXIMATELY
THE EXTENT
of the
UPPER MARINE SEA
in
NEW SOUTH WALES
+ Areas of Upper Marine Sedimentation


Warwick
QUEENSLAND
Drake
Ashford
Clarence R
Inverell
Grafton
Main Divide
LAND
Macleay R
Gunnedah
Breeza
Hastings R
Murrurundi
Manning R
Muswellbrook
Gulgong
Singleton
Maitland
Mudgee
Rylstone
Hunter R.
Newcastle
Wallerawang
Lithgow
Hawkesbury R
SYDNEY
Wollongong
Kiama
Nowra
Shoalhaven R
Present Main Divide
Clyde R
MAP
SHOWING APPROXIMATELY
THE EXTENT
of the
INLAND SEA
in which were deposited
THE UPPER COAL-MEASURES
o Outcrops of Upper Coal Measures

[*From the Proceedings of the Linnean Society of New South Wales, 1913, Vol. xxxviii., Part 1, April 30th.*]

# NOTES ON SOME RECENTLY DISCOVERED OCCURRENCES OF THE PSEUDOMORPH, GLENDONITE.

By A. B. Walkom, B.Sc., Linnean Macleay Fellow of the Society in Geology.

(Six text-figs.)

While examining the Lower Marine Series along the main northern road, in the vicinity of Harper's Hill (Allandale), I observed a number of specimens of the pseudomorph, Glendonite, in two large boulders by the roadside. These were thought, at the time, to have been carried there from some other locality, but inquiries, made of some of the residents, showed that they had come from the road-cutting close by. Further search was then made, and specimens were soon found *in situ*. This discovery was of considerable interest, for, although glendonite had been recorded from a number of localities previously, all the occurrences were in

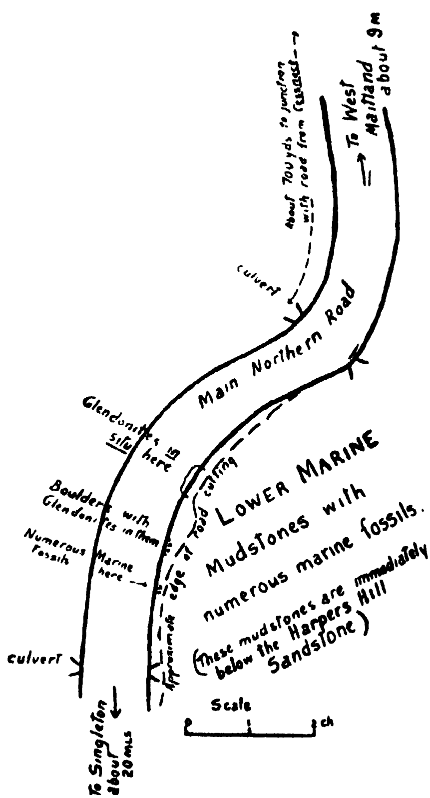



**Fig. 1.—Sketch showing locality where Glendonites were found in the Lower Marine Series.**

the Upper Marine Series, and it had never been found in the Lower Marine Series. A number of specimens were collected, and examined to see whether they presented any differences from those previously described. Mr. W. S. Dun kindly exhibited specimens of these crystals for me, at the meeting of this Society held in August, last year.

In a paper on "The Occurrence of the Pseudomorph Glendonite in New South Wales," by Professor David, Dr. Woolnough, and Messrs. Taylor and Foxall,* a complete review of previous literature was given; and for a bibliography, the reader is referred to that paper. They described the occurrence of glendonite at four localities, representing four separate horizons in the Upper Marine Series, as follows†:—

(a) Glendon, 5 miles E.S.E. from Singleton. Horizon approximately 200 feet above the Muree Beds. The glendonites here occur singly or in groups, and are from 3 to 12 inches in length.

(*b*) Left bank of Hunter River, at Railway Bridge, Singleton. Horizon about 1,000 feet above the Muree Beds. One glendonite recorded from here, is composed entirely of ferruginous gypsum.

(*c*) Mount Vincent, 14 miles south of East Maitland. Horizon 700 feet above the Muree Beds. The glendonites here frequently take the form of hollow casts in the centre of an oval or elliptical concretion. They occur singly or in aggregates.

(*d*) Huskisson, Jervis Bay. Horizon about 200 feet below the Nowra Grit, which is the equivalent of the Muree Beds.

The size varies from an inch to over fourteen inches in length.

In 1908, Mr. J. E. Carne‡ discovered glendonites on another horizon, in the Upper Marine Series, namely, about 350 feet above the top seam of the Greta Coal-Measures at Muswellbrook. These glendonites are of the large type, measuring up to 9 inches and

* Records Geol. Surv. N. S. Wales, 1905, viii., pp.161-179.

† The following details of these four horizons are taken from the paper mentioned above, pp.166-169.

‡ Ann. Report Dept. of Mines N. S. Wales, 1908, p.166. (The plan and sections accompanying this report, were printed in the Annual Report for 1910, facing p.176)

more in length, and 2 to 3 inches in diameter. Both simple and compound types occur, the latter being apparently haphazard intergrowths of two or more individuals.

In 1910, Dr. W. G. Woolnough* discovered a zone of glendonite pseudomorphs in an argillaceous limestone, on the road from Singleton to Dyrring, near the southern branch of Wattle Ponds Creek. This horizon is about 1,480 feet below the base of the Muree Beds. The crystals there are of the small, composite type.

During 1912, Professor Woolnough† found glendonites associated with *Chænomya* in the topmost part of the Upper Marine Series at Wollongong. These were in the form of hollow moulds in the centre of concretions, similar to those which are found at Mt. Vincent. The base in which these concretions occur, is a tuffaceous sandstone.

In his report on "The Tasmanite Shale-Fields of the Mersey District," Mr. W. H. Twelvetrees‡ has recorded the occurrence of glendonite in the mudstones above the Tasmanite Shale-deposit. The Shale is considered, by him, to be on the same horizon as the Greta Coal-Measures in New South Wales, so that the horizion of the glendonite-occurrence in Tasmania, corresponds to the lower part of the Upper Marine Series in New South Wales. In the only specimen that I have seen from the Tasmanian locality, the glendonites are of the smaller type, and are bunched together in complex aggregates.

The occurrence which forms the main subject of this note, is on the main northern road, nearly half a mile beyond the junction of that road with the road from Allandale Railway Station. (See sketch, Fig. 1, p. 160).

The horizon of these beds is 2,800 feet above the base of the Lower Marine Series, and is nearly 2,600 feet below the lowest recorded horizon. It is about 150 feet below the well-known Harper's Hill, green, tuffaceous sandstone.

* Journ. Proc. Royal Soc. N. S. Wales, 1910, xliv., pp. 557-559.

† Professor Woolnough very kindly gave me this information of his discovery at Wollongong.

‡ Dept. of Mines, Tas., Geol. Survey Bulletin, No. 11, 1912, p. 54.

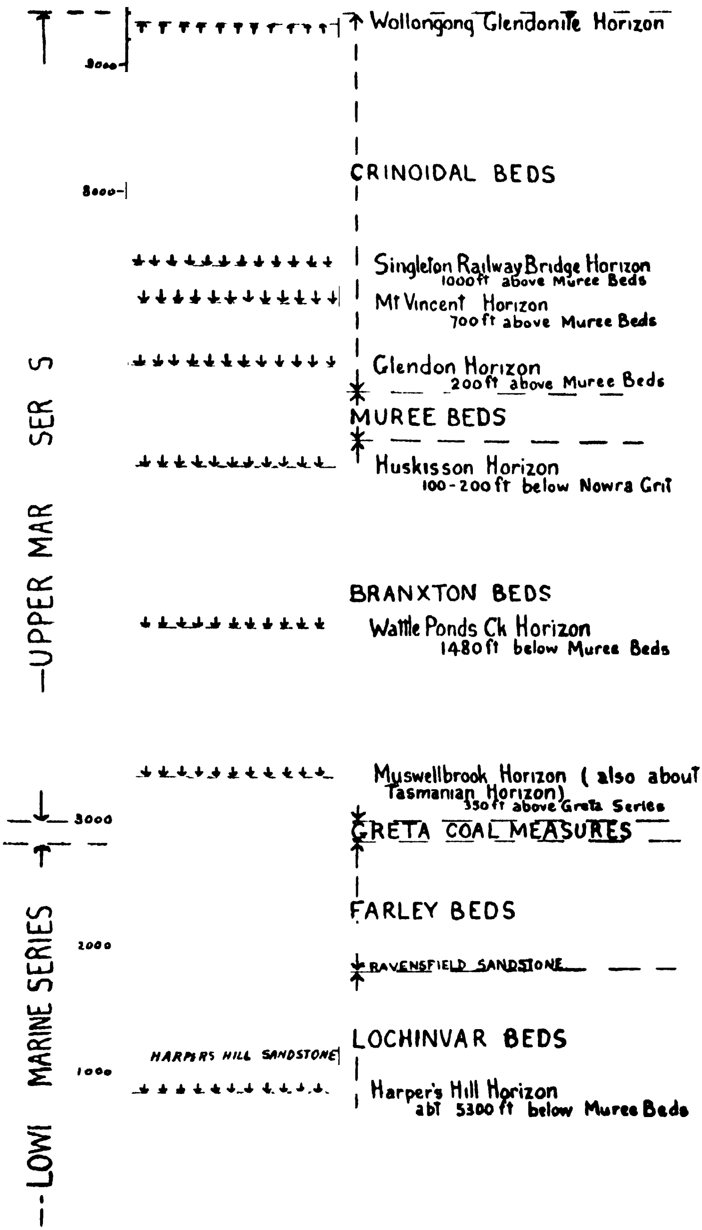



**Fig. 2.**—Vertical Section of part of the Permo-Carboniferous System, showing glendonite-horizons.

The glendonites here are imbedded in a light-coloured, micaceous mudstone, which is rather calcareous, and contains numerous marine fossils, *e.g.*,

| | |
|---|---|
| Plant-stem. | *Mæonia*, 3 spp. |
| *Spirifer vespertilio* G. Sby. | *Pleurophorus* sp. |
| *S. tasmaniensis* Morris. | *Pachydomus* sp. |
| *Martiniopsis subradiata* Sby. | *Mourlonia rotundata*(?). |
| *Chænomya* sp. | *Keeneia*(juv.). |
| *Edmondia*(?) *nobilissima* de Kon. | *Conularia lævigata* Morris. |
| *Deltopecten subquinquelineatus* McCoy; two vars. | |

Fig. 2 (p. 163) is a vertical section of part of the Permo-Carboniferous system, showing the position of the various glendonite-horizons.

*Chemical.*—The substance of these pseudomorphs was found to be almost entirely soluble in hydrochloric acid; and qualitative analysis showed that they consist almost wholly of calcium carbonate, and also that there is an absence of both sulphates, and barium. The composition, then, is no doubt very similar to those analyses by Mr. B. V. Barton, B.E., quoted in the paper mentioned above,* and a quantitative analysis was not considered necessary in this case.

*Crystallographic.*—The crystals are all of similar type to those described from Singleton and Glendon, but are somewhat smaller, averaging from 2 to 2·5 inches in length and 0·75 inch in diameter. They are mostly simple crystals, but a number are of the composite type. Of those which are not simple, the majority are like that figured (Fig. 4), *i.e.*, an intergrowth of two individuals, while a few are much more complex, there being as many as eight individuals bunched together. The frequent occurrence of the first of these two types, namely, intergrowths of two individuals, suggested the possibility of twinning. That they are not twinned, however,

Fig. 4—Photo of simply twinned glendonite crystal (about nat. size).

* Rec. Geol. Survey N. S. Wales, viii., pp. 170-172.

seems to be shown by the fact, that an examination of three different specimens of this type, showed the relative orientation of the two individuals to be different in each case.

The crystals all show distinct curving of some of the faces; the prism-faces are generally plane, and give straight edges, but the pyramid- and dome-faces are decidedly curved. In measuring the curved faces, the method used by Anderson and Jevons,* in measuring opal-pseudomorphs from White Cliffs, N.S.W., was followed, namely, "making the goniometer-arms tangent to the part of the faces close to the edges."

Glauberite has been suggested as the probable original mineral for these pseudomorphs, and all the measurements of these crystals, from the Lower Marine Series, tend to confirm that suggestion.

The habit is monoclinic, and measurement shows that there are three forms present, the angles between homologous faces of which are, 94°, 63·3°, and 67°. These three forms correspond fairly well with with *m*(110), *s*(111), and *f*(023) of glauberite. Two of these forms were described on the crystals from Huskisson,† but on these crystals, the clino-dome present was *g*(021), while on the crystals now being discussed, the clino-dome is *f*(023). The following table shows the measurement of interfacial angles, compared with those of glauberite:—

| Normal Angles. | No. of readings | Limits. | Mean. | Average. | Angles for Glauberite |
|---|---|---|---|---|---|
| $(1\bar{1}0)\wedge(110)$ | 9 | 91°-97° | 95° | 94° | 96° 58′ |
| $(\bar{1}10)\wedge(\bar{1}\bar{1}0)$ | 8 | 90°-94½° | 92·3° | | |
| $(111)\wedge(1\bar{1}1)$ | 8 | 59½°-67° | 63·6° | 63·3° | 63° 42′ |
| $(\bar{1}\bar{1}\bar{1})\wedge(\bar{1}1\bar{1})$ | 9 | 60½°-66½° | 63·1° | | |
| $(023)\wedge(0\bar{2}3)$ | 9 | 63°-68½° | 66·3° | 67° | 64° 46½° |
| $(0\bar{2}\bar{3})\wedge(02\bar{3})$ | 9 | 64°-70° | 67·7° | | |

* Rec. Austr. Museum, vi., 1905, p.33.

† *Op. cit.*, p.175.

The measurement of the angles between $s$ and $f$, and $s$ and $m$ was too unsatisfactory, on account of rough and curved surfaces. Fig. 3 is an ideal stereographic projection of one end of a crystal with the three forms developed.

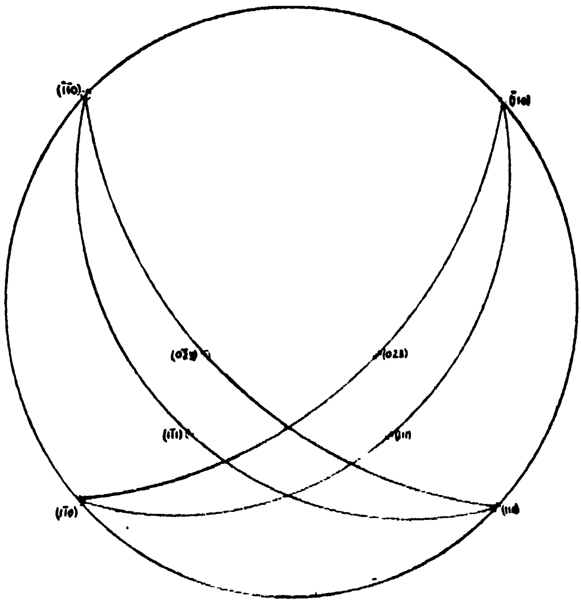



Fig. 3.—Stereographic projection of one end of a glendonite-crystal.

A number of the crystals show a series of parallel striations, representing the trace of a cleavage (Figs. 5-6). In some cases, these striations persist along the whole length of the crystal, over forms which are not in one zone, and so cannot represent oscillatory combinations. The angle between the plane of these striations and the edge (110) (1$\bar{1}$0), was easily calculated, and proved to be approximately 66°. If the original mineral were glauberite, the cleavage is perfect, parallel to (001), so that the angle just measured, would represent $\beta$. In glauberite, $\beta$ is 67° 49′ 7″, so that the angle obtained for these glendonites, is quite as close as could be expected from contact goniometer-measurements.

*Petrology.*—Only one crystal was sectioned for the microscope. It consisted almost completely of granular calcite. A small proportion of the calcite-grains are clear and colourless, but most of them are of a cloudy-brown colour. A few small fragments of quartz were observed.

*Summary and Conclusions.*—All the observations made on these glendonites from the Lower Marine Series, confirm the conclusion

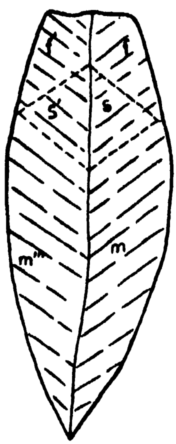



Fig.5.—Freehand drawing of glendonite crystal, showing direction of striations (front view : about nat. size).

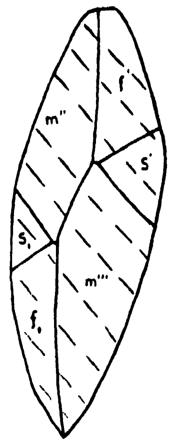



Fig.6.—Same as Fig.5 (side view : about nat. size).

arrived at by Professor David, Dr. Woolnough, and Messrs. Taylor and Foxall, that the original mineral, of which they are replacements, was glauberite.* Nothing has been observed which conflicts with their conclusions, excepting numbers (v.) and (vi.).†

With regard to (v.), which is as follows, "The presence of numerous erratics indicates that these waters were occasionally chilled by floating ice," it may be stated, that three, of the four newly-discovered occurrences of glendonite, are on horizons which

* *Op. cit.*, p.179. † *Op. cit.*, p.178.

are not considered to have been formed under glacial conditions. The newly-discovered occurrences also do not agree with the statement in conclusion No. (vi.) that "The horizons of the glendonites are not far below, in some cases close to, the top of the highest beds of a Marine Series, etc."

Glendonite has now been recorded from seven horizons in New South Wales, and one in Tasmania. These horizons are scattered at intervals, through a thickness of strata amounting to about 7,000 feet. This shows that the conditions, which governed the crystallisation of glauberite (for it is almost certain that this was the original mineral), must have been of fairly frequent occurrence in the Permo-Carboniferous seas; and it also shows that the occurrence of the pseudomorphs is of no value as an indicator of any particular stratigraphical horizon.

Glacial conditions were of frequent occurrence during Permo-Carboniferous time, and Professor Woolnough has suggested, in conversation about these pseudomorphs, that these conditions may have played an important part in the production of conditions suitable for the formation of glauberite; and that if this could be established, then the occurrence of glendonite, pseudomorphic after glauberite, might be taken as an indication of glacial conditions. This suggestion, taken with the fact that the glendonites always occur in a calcareous mudstone, opens up an interesting field of research in the artificial preparation of glauberite, (which, as far as could be ascertained, has not yet been prepared artificially in the wet way), by attempting to grow the crystals in calcareous mud, under temperature-conditions approximating to those which would be prevalent in waters subject to chilling by glaciers.

I wish to express my thanks to Dr. C. Anderson, of the Australian Museum, for the advice he most willingly gave me in connection with the crystallographic part of this note; and to Professor Woolnough for kindly volunteering part of the information contained in the paper, and for suggestions made in discussing the subject with me.

# NOTES ON THE GEOLOGY OF WEST MORETON, QUEENSLAND.

By R. A. WEARNE, B.A., and W. G. WOOLNOUGH, D.Sc., F.G.S.

[*Read before the Royal Society of N. S. Wales, August 2, 1911.*]

**I. Introduction.**– The area designated in this paper as the West Moreton District extends from the Brisbane River on the north, to the McPherson Range on the south, and from the Logan River on the east to the Main Dividing Range on the west.

Dr. H. I. Jensen, in his paper on the Alkaline Rocks of Southern Queensland, at the Brisbane Meeting of the Australasian Association for the Advancement of Science, referred to the Main Dividing Range as the Little Liverpool Range. In the following remarks the title Little Liverpool Range is applied to the spur of the Main Range that runs from Mount Castle northwards, and is crossed by the Brisbane–Toowoomba Railway Line between Grandchester and Laidley.

**II. Work of Previous Observers.**—The northern border of the area under discussion has formed the subject of a monograph by Cameron.[1] In this report the general sequence of the Ipswich Coal Measures is worked out, but no description is given of the volcanic series which forms the subject of the present paper.

Jensen[2] has studied the volcanic series. He describes a number of rock types, particularly from Mounts Flinders

[1] Cameron, W. E.—Geology of the West Moreton or Ipswich Coalfield. Geol. Survey of Queensland, Rep. 1899.

[2] Jensen, H. I.—Notes on the geology of the Mount Flinders and Fassifern Districts, Queensland, Proc Linn. Soc. N.S.W., Vol. xxxiv, 1909, pp. 67 – 104; also The Alkaline Rocks of Southern Queensland, Rep. Aust. Assoc. Adv. Science, Brisbane, 1909, pp. 249 – 258.

and French. These he assigns to a variety of alkaline lavas. He is of opinion that "the volcanic rocks of the Fassifern Scrub are all Post-Triassic and probably Post-Cretaceous." He describes the area under consideration as a senkungsfeld and gives a detailed account of the tectonic geology.

Marks[1] is of opinion that the age of the volcanic series in the neighbourhood of Beaudesert is Trias-Jura, in which idea he follows Rands.[2]

In an account of Mount Lindsay in the Macpherson Range Andrews describes the eruptive trachytes as Trias-Jura in age.

It will be seen then that considerable diversity of opinion exists in connection with this important question.

**III. Physiography.**--The contour of the Main Dividing Range which separates West Moreton from the Darling Downs reveals the fact that two successive uplifts occurred, the first an uplift of about 2,000 feet, and the second of about 2,700 feet. The summits of the Main Range—Mounts Castle (3,700 feet), Cordeaux (4,100 feet), Mitchell (4,000 feet), Spicer (4,100 feet), Huntley (4,150 feet), Roberts (4,350 feet), and Wilson (4,060 feet) are practically at a uniform height above sea level. They represent the denuded remnants of an uplifted peneplain. The uniform level of this uplifted peneplain can be seen from the summit of Mounts Spicer and Mitchell gently sloping westwards across the Darling Downs.

Four well defined "air gaps" occur between Spring Bluff and Bald Mountain, Mounts Cordeaux and Mitchell, Mounts

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[1] Marks, E. S.—Coal Measures of South East Moreton, Queensland Geol. Survey, Publ. No. 225, p. 52, Brisbane 1910.

[2] Rands, W. H.—Report on the Albert and Logan District, Qeensland, Parl. Papers. C.A. 5, p 2, Brisbane, 1889.

[3] Andrews, E. C—A Preliminary Note on the Structure of Mount Lindsay. Rec. Geol. Surv. N.S.W., Vol, VII, 1903, pp. 328 – 240.

Mitchell and Spicer, and Mounts Roberts and Wilson. They represent the U-shaped mature river valleys eroded to base level, which have since been elevated to a height of about 2,700 feet above sea level. Cunningham's and Spicer's Gaps still preserve a perfect U-shaped contour, the latter being one and three quarter times the size of the former. A magnificent view of these "gaps" can be obtained from the western side of "Jump Up," a high ridge which runs to the north of Mount Alford about six and a half miles to the west of the township of Boonah. The gap between Spring Bluff and Bald Mountain has been faulted to a depth of about 500 feet below the uplifted peneplain, whereas Cunningham's, Spicer's and Wilson's Gaps are on the edge of the escarpment. These gaps have at the present time an important influence upon the meteorology of the eastern coastal plain.

In Cainozoic times the Water Divide existed far to the east of its present position, and four important western flowing streams carved the U-shaped valleys of the aforesaid gaps to base level. The most northern of these rivers followed somewhat the course of the Lockyer and Murphy's Creeks and flowed through the Spring Bluff gap near Toowoomba. Its tributaries on the left bank carved the aggraded U-shaped valleys through which Blenheim Creek and Laidley Creek now meander, and the rich agricultural lands of the famous Lockyer District are the result of their work. The second river flowed west through Cunningham's Gap, and one important tributary on the right bank is represented by the magnificent V-shaped gorge of Reynold's Creek, which cleaves Mount Edwards. This gorge is at present about two miles long, its sides slope at an angle of 40°, and the summit of the V on the east is 1,000 feet above the bed of Reynold's Creek, and that on the west 1,800 feet. It much resembles the famous Upper Shoalhaven River

Gorge of New South Wales in appearance. The third stream ran roughly parallel to the second, divided from it by Mount Greville, and flowed through Spicer's Gap. The fourth stream followed the upper valley of the Teviot, flowed through Wilson's Gap, and thence along the upper course of the Condamine through the gorge known locally as "Sydney Heads."

**IV. Earth Movements.**—In Cainozoic times the district was reduced to a peneplain level. It was next elevated to a height of about 2,000 feet, and the mature river valleys referred to above were worn to base level in the volcanic products. This is proved by the uniform depth of the U's below the summit level. A second uplift of about 2,700 feet next occurred in late Cainozoic time, as proved by the fact that the uniform level of the 'air gaps' is at the same height above sea level. The comparative recency of the movement is indicated by the very slight alteration in form suffered by the uplifted valleys since their elevation.

Extensive trough faulting then occurred between Indooroopilly near Brisbane and the Main Range. The first faulting probably resulted in the production of what we call the *Lockyer Fault Block*, bounded on the west and south by the Main Dividing Range, and on the east by the escarpment of the Little Liverpool Range. This block is traversed by four meridional ridges:—the Little Liverpool Range, the Mount Mistake Range, the Hip Roof, and another of unknown name, with horizontal crest lines rising to a uniform level of about 2,000 feet. Immediately to the east of Toowoomba this faulting carried down a portion of the old mature valley about 500 feet below its original level. The faulting here was somewhat complex, and this fault is associated with one or more others increasing the total throw.

The second period of movement produced the *Fassifern Block* lying to the east of the Little Liverpool Range and the approximate collinear portion of the main range to the south of the junction. This fault probably amounted to about 900 feet. The throws of these faults have been calculated from the following evidence:—

i. The mature topography of the main range near Toowoomba is continued to the east near Spring Bluff at a lower level of about 500 feet.

ii. At the main range near Toowoomba basalt caps the coal measures at an altitude of 1,700 feet above sea level. It can be clearly seen from the railway line at the ninety-three mile post from Brisbane. Throughout the Lockyer Block a similar flow of basalt up to 600 feet in thickness caps the coal measures in each of the four ridges at a height of 1,200 feet above sea level.

iii. At Mount Walker, a peak belonging to the Fassifern Block, basalt also caps the coal measures, but at a height of only 300 feet above sea level.

This evidence is supported by the appearance of the sandstones and grits of the coal measures in the railway cuttings along the main range and the Little Liverpool Range. At the ninety-one mile post near Spring Bluff the slickensided surface of the fault scarp can be clearly detected. Between the first and second railway tunnels in the Little Liverpool Range a marked change in the dip can be noticed along the line of fault, and slickensided surfaces were found in the grits and sandstones. One mile to the west of Ipswich the coal measures are tilted at an angle of 80°, and the Bremer River follows the line of fault for a distance of over two miles from Berry's Lagoon to Coal Falls.

## V. Geology—(I) Sedimentary Rocks.

(a) *Permo-Carboniferous Rocks.*—An inlier of Permo-Carboniferous rocks is to be found immediately to the north-west of Mount Barney, a high double peaked mountain, which is situated about six miles to the north-north-west of Mount Lindsay. These rocks have been previously considered as of Trias-Jura age, but the discovery of a definite specimen of *Fenestella fossula*, Lonsd., submitted to Mr. W. S. Dun for identification places them in the Permo-Carboniferous. This is the first record of Permo-Carboniferous fossils in the West Moreton District.

(b) *Trias-Jura Rocks.*—The representatives of the Trias-Jura rocks met with in the area under consideration are to be referred to the Walloon stage. They consist of conglomerates, grits, sandstones, and shales with thin seams of coal. The coal measures form rather poor soil, and the surface ridges are mostly used for grazing purposes.

## (II) Eruptive Rocks.

Four distinct periods of volcanic eruption can be traced in the West Moreton District by the occurrence of:—

1. Trachytes.
2. Andesites and Dacites.
3. Rhyolites.
4. Basalts.

### 1. Trachytes.

Trachyte eruptions occurred along a zone running from the main range to Mount Cordeaux in an easterly direction to Redbank Plains, about eight miles south-east of Ipswich. These eruptions produced a number of cones, whose denuded remnants may now be seen at the summits of the main range and at Mounts Matheson, Greville, Edwards, French, Flinders, and the ridge to the south of Redbank Plains. The flow of this period attained a thickness of about 2,000 feet.

*Mount Flinders.*—The trachyte series at Mount Flinders (2240 feet) can be subdivided into three distinct sub-periods of eruption. The first produced the dark basic looking trachyte (pantellarite of Jensen). It has a characteristic greasy looking lustre much like phonolite. The lower hills on the the northern side of Flinders are composed of this rock. The second sub-period produced the light alkaline felspar porphyry which composes Flinders and a number of the neighbouring peaks. Two distinct dykes of this light trachyte run from Flinders through the pantellarites, one to the north-west of that mountain, 20 feet wide, shewing well defined horizontal prismatic structure. The third sub-period produced a pitchstone porphyry containing phenocrysts of sanidine embedded in a black glassy matrix. (See petrographical descriptions.)

*Mount Blaine* about two miles to the north of Mount Flinders is composed entirely of this material *with inclusions of light and dark trachyte.* One inclusion of the light variety measured 6″ × 4″, and another of pantellerite 5″ × 4″.

*Ivory's Rock* which can be seen about three miles to the east of the Rockton Railway Station, standing like a large obelisk above the plain, is about 1,300 feet high, and is composed entirely of trachyte breccia. At a point 400 feet from its summit the angular masses of breccia are cemented in a matrix of trachyte glass which seems to have forced its way from the centre of eruption through the porous masses of scoria.

*Main Dividing Range.*—The main range near Cunningham's Gap is composed of alkaline trachyte capped by olivine basalt. *Mount Matheson* (2,660 feet) appears to have been the main focus of the trachyte eruption of this district. Its summit consists of vesicular trachyte surrounded on all sides by huge masses of trachyte tuff, breccia

and conglomerate containing angular masses three feet in diameter. A steep escarpment exists to the north and west, and a ridge connects this mountain on the southern side with the lower slopes of Mount Mitchell. Johnston Creek and Clayton Gully rise in the elbow thus formed. A perfect view of the well defined U-shaped mature valley of Cunningham's Gap can be seen from the summit of Mount Matheson.

*Mount Mitchell* (4,000 feet).--A splendid section of the volcanic series and the associated sedimentary rocks is revealed in Gap Creek (the eastern one of this name) and the wonderful escarpment of Mount Mitchell itself. The Walloon stage of the Ipswich coal measures is distinctly intruded and capped by trachyte, and these in turn by basalts. A fairly thick seam of coal outcrops about one mile below the "Second Falls." It is intruded by a dyke of basalt which has opened out into a sill along the seam. Several basalt dykes occur running roughly north and south at right angles to the creek, and each in turn causes the formation of a pretty waterfall.

*Cunningham's Gap* consists of a perfectly shaped U situated between Mounts Cordeaux and Mitchell, the trough being 1,500 feet below the summits of those mountains. It presents one of the finest examples of an Air Gap to be seen in any part of Australia. At the lowest point of the gap trachyte breccia is met with. The base of Mount Mitchell is composed of alkaline trachyte, tuff and breccia for a thickness of about 1,500 feet, and this in turn is capped by about 1,000 feet of basalt. The entire thickness is made up of a very considerable number of independent beds of volcanic material, each one practically horizontal. The summit of Mount Mitchell consists of a narrow ridge running north and south. Viewed from the east it shows a broad rounded summit with a vertical escarpment of about

2,000 feet. From the south it appears as a huge inaccessible pinnacle. The narrowest part of the summit is not more than nine feet across, and a stone can be dropped on the eastern side for a depth of at least 1,500 feet before striking the rock face, while on the western side there is a similar cliff of about 500 feet. From the summit of the mountain an excellent view of the low lying Fassifern Block can be obtained, and beyond the hills around Ipswich, which bound the block on the east, the waters of Moreton Bay are visible.

*Mount Greville* (2,700 feet) the sentinel of "The Gap," situated about five miles to the east of the Main Range, is composed of grorudite, and its present contour is probably due to the erosion of the mature rivers that formerly flowed through Cunningham's and Spicer's Gaps. The northern slope corresponds in contour with the southern slope of the former, while the southern contour recalls the outlines of the northern slope of the latter.

The eastern side of Mount Greville is cleft by fissures from 6 feet to 20 feet wide with precipitous walls from 100 feet to 200 feet in height. They have been formed by basalt dykes which being less resistant than the grorudite have been completely eroded. These clefts are studded with magnificent palms, ferns, and orchids, and form one of the most picturesque spots in Southern Queensland.

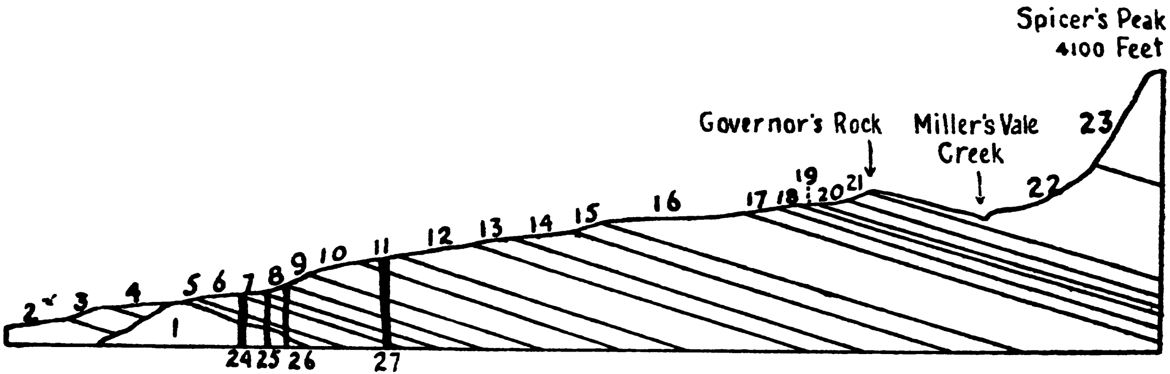
*Mount Edwards* (2,300 feet) is composed of trachyte intruded by basalt, and *Mount French* (1,800 feet) is composed of comendite, tuffs and breccias.

*Spicer's Peak* (4,100 feet) presents a section almost identical with that of Mount Mitchell, and like the latter has a vertical escarpment on the east.

## 2. Andesites and Dacites.

A parasitic cone of andesite occurs along the old Warwick Road which runs through Spicer's Gap (See Fig. 1). Here

Fig. 1—*Section of Main Range along Old Warwick Road,*




Horizontal Scale ——— 1000 Yards : Vertical Scale ——— 1000 Feet

Tri: Ju: ndstone and quartzite
Trachyte tuff and breccia
3. Trachy
4. Tuff
5. Tuff
6. achyte

7.
8. Trac yte
9. Coar e trachytic agglomerate
0. Basic trachyte
1. Trachyte tuff
2. Basic trachyte
3. Amygdaloidal trachyte

T
T chyte
Trachyte uff nd reccia
7 Basic trachyte
8 Trachyte
9. Basalt sill
20 Trachyte

21. Trachyte tuff
22. Trachyte tuffs
23. Olivine basalt
24. Phonolite dyke
25. Basalt dyke
26. Basal lyke
Andesite probably parasiti

there is distinct evidence that the andesite intrudes and caps the trachyte.

*Mount Alford* (2,200 feet) about three miles to the east of Mount Greville is composed of andesites, quartz-diabases and devitrified obsidians, etc., intruded by rhyolite dykes. This mountain presents a fine field for research work and holds the key to the volcanic sequence. It is hoped that a detailed examination will be made later.

*Mount Maroon* (3,300 feet) about 12 miles to the E.S.E. of Mount Alford is composed entirely of rhyolite. Two features are here worthy of note (1) the occurrence of huge vertical prisms 150 feet high on the northern side of the summit, and (2) the presence of two small but very deep elliptical lakes near Mr. Rose's Farm on the mount side. These lakes are surrounded by rhyolite breccia and tuffs, and have never been known to be dry. The larger one is 150 yards long by 75 yards wide.

*Mount Barney* the culminating peak of southern Queensland, 4,625 feet high, is also composed of rhyolite, intruded by basalt dykes. It is situated between Mount Maroon and the McPherson Range.

### 3. Rhyolites.

A large rhyolite dyke intrudes trachyte at Johnston Creek, about one mile to the west of Mr. Anderson's house "Marraboola," in portion 92 V, Parish of Clumber.

*Glennie's Pulpit* consists of the plug of rhyolite on the north-western side of Mount Alford. It stands about 120 feet above the contour of Mount Alford, and is composed of practically horizontal hexagonal prisms, pointing to a vertical conduit for the molten magma. It is surrounded by acid tuffs and breccias and represents a centre of rhyolite eruption.

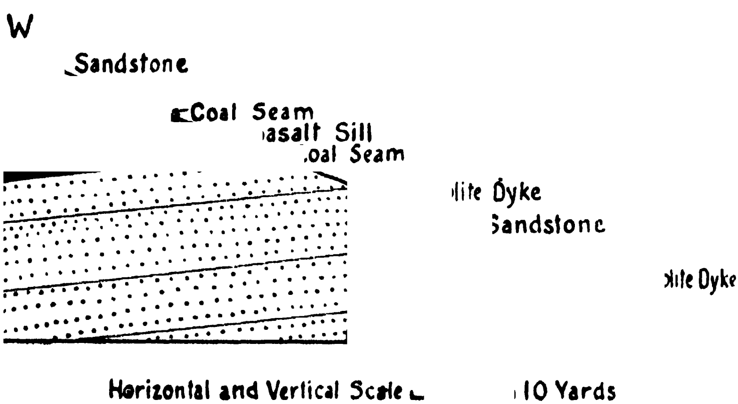
### 4. Basalts.

Basalt intrudes and caps trachyte along the Main Dividing Range near "The Gap." Basalt dykes intrude trachyte at Mounts Greville, Edwards, French and Flinders. Basalt dykes intrude andesite at Mount Alford, and basalt dykes intrude rhyolite at Mount Barney.

A striking difference is presented between the relationship of the basalt dykes to the streams near the Main Range and at Mount Barney. At the former locality the dykes cross the streams at right angles, whereas at Mount Barney the streams are subsequent and follow the course of the dykes. Basalt seems to have been extruded throughout the whole district by fissure flows.

At the Main Range near Toowoomba two distinct dykes of large dimensions can be seen along the eastern escarpment—one at the 93 mile post on the railway line from Brisbane, 200 yards in thickness, and the other at the 91 mile post exposing a width of 600 yards in the railway cutting. Intrusive sills of basalt occur on the Main Range along the old Warwick Road at an altitude of 2,040 feet, and at the "Jump Up" see figs. 1 and 2.

Fig. 2.



*Limestone Hill* (Ipswich) has been formed by a fissure flow of basalt and it consists of a brown decomposed basalt, white trap, silicified breccia which has been rebrecciated, and basalt.

*Red Hill* forms the western portion of the same flow, the fissure running through the Golf Park.

**Age of Volcanic Rocks.**

Trachyte and basalt intrude and cap the Trias-Jura Coal Measures throughout the whole of the volcanic zone from the Main Range to Redbank Plains and portions of the Trias-Jura rocks can be found embedded in the volcanic breccias at Mount French and Ivory's Rock. Thus at first sight one would naturally conclude that the whole of the volcanic eruptions were Post Trias-Jura.

After very careful search along the Blenheim Creek valley and also in the deep gullies at the base of Mount Flinders and Mount Alford, waterworn volcanic pebbles were found embedded in an extensive bed of conglomerate which occurs near the top of the Walloon Series. This conglomerate is capped by grits and sandstones for a thickness of about 150 feet.

At the "Hip Roof" referred to above, a large piece of volcanic tuff was found associated with basalt containing fossil imprints of Trias-Jura plants. One specimen submitted to Mr. W. S. Dun for identification was stated to be *Taeniopteris Daintrei*. There seems thus to be conclusive evidence that at least some of the volcanic eruptions of West Moreton were of Trias-Jura age. This agrees with the evidence published by Andrews and Marks.

Field evidence seems to support the conclusion that there have been two distinct and separate series of volcanic eruptions in the West Moreton District:—

(1), of Trias-Jura Age contemporaneous with the Walloon stage of the Ipswich Coal Measures and including the more normal trachytes of the Main Range, Mounts Edwards and Flinders and the basalts of the Main Range near Cunningham's Gap, and

(2), of Tertiary Age including the more alkaline trachytes of Mounts French and Greville, the rhyolites of Mounts Maroon and Barney, and the basalts of the Toowoomba Range.

**Summary.**

1. At least two levels of erosion are to be recognised in West Moreton, standing respectively at an altitude of 2,600 feet and 4,000 feet.

2. Extensive block faulting has occurred, giving rise to what we have termed the Main Range Fault, the Lockyer Block, and the Fassifern Block.

3. An area of fossiliferous Permo-Carboniferous is shewn to exist near Mount Barney.

4. The volcanic sequence is:—

   i. Trachyte
   ii. Andesites and dacites
   iii. Rhyolites
   iv. Basalts

5. The ages of the volcanic eruptions believed to belong,
   i, to the Walloon stage of the Trias-Jura Coal Measures, etc.
   ii, to the Tertiary Period.

**Petrographical Notes.**

*Granophyre, Mount Alford.*—Allotriomorphic granular rock with very conspicuous granophyric structure. Essential constituents, plagioclase, anorthoclase, quartz, alteration products of ferromagnesian minerals, ilmenite and apatite. Exclusive of the granophyric fibres, the average

grainsize of the rock is even, about 1 mm., though individual crystals rise to about 2 mm. in length. The plagioclase is subidiomorphic in form and includes the largest crystals in the rock. It is twinned on the albite law and occasionally on the Carlsbad law as well. Here and there a little pericline twinning is developed also. The composition is that of an acid labradorite. There is also abundant felspar quite allotriomorphic, untwinned or very hazily twinned, with refractive index less than, or equal to that of Canada balsam, and less than that of quartz. This appears to be anorthoclase. It is granophyrically intergrown with quartz. In some instances there is a large grain of the felspar with a fringe of granophyre; in others the granophyric structure extends to the centre of the crystal; while in others there is a nucleus of quartz with a fringe of granophyre, but this last arrangement is not common. Some independent grains of quartz occur, but this mineral is mostly intergrown with anorthoclase as above described.

The arrangement of the ilmenite is one of the most remarkable features of the slide. It is abundant in thick tabular sections, sometimes simple, sometimes intergrown with the ferromagnesian mineral, and *sometimes forming a perfect granophyric intergrowth with quartz and felspar.* The ferromagnesian mineral (probably augite) is completely altered, and is represented by an aggregate of fibrous uralite, dark green and pleochroic. Apatite is fairly abundant in thin needles. Order of consolidation:—

Apatite
Ilmenite
Augite
Plagioclase
Anorthoclase
Quartz

*Granophyre*, near base of Mount Alford on the northern side.—The rock is granophyric with pseudo-porphyritic nuclei of quartz, orthoclase, anorthoclase(?), and haematite. Individual grains of the various minerals are up to 4 mm. diameter, but mostly are much smaller. Haematite is always enclosed in the other minerals and probably represents the alteration product of original magnetite. Felspar is considerably kaolinized. Some is definite orthoclase, but some appears to have higher refractive index and shows very fine and hazy albite twinning. Sometimes quartz, sometimes felspar forms the nucleus round which a granophyric intergrowth is formed.

*Mount Alford*.—There is a marked variation in texture within the limits of the microscope slide but the line of demarcation is not very sharply drawn.

The finer grained portion is cryptocrystalline and spherulitic with occasional granophyric patches, very much clouded by decomposition products. There are occasional phenocrysts of plagioclase, and grains of magnetite up to 0·5 mm. diameter.

The coarser portion has a fine base composed of untwinned felspar (orthoclase ?), with a little quartz, chlorite and magnetite and very little trace of granophyric structure. In this part occur abundant plagioclase phenocrysts and grains of titaniferous magnetite very irregular in shape and much intergrown with the ferromagnesian constituent. The latter is represented by green fibrous uralite.

The plagioclase phenocrysts appear to be the same in both portions. They are idiomorphic, twinned after albite and Carlsbad laws mostly, with occasional patches showing pericline lamellæ, and must be referred to acid labradorite.

In the coarser portion there occur, fairly abundantly, rounded grains of quartz and also one little nest of quartz

and calcite. This latter is undoubtedly an inclusion of calcareous sandstone and the isolated grains of quartz appear to have a similar origin. The whole rock is much impregnated with calcite.

It is probable that the coarse and fine portions represent "schlieren" in a non-homogeneous magma.

*Foot of Mount Greville.*—Porphyritic rock with an even-granular base averaging about 2 mm. The base contains quartz and orthoclase in about equal amounts together with alkaline amphiboles in considerable abundance and apparently of several varieties. Among these amphiboles we have:—

i. Ophitic patches of strongly pleochroic dark green to brilliant indigo riebeckite. This encloses idiomorphic quartz and felspar grains.

ii. Irregular prisms with ragged ends and sides, pleochroic in dark brown to bluish-green tints. It is most difficult to obtain suitable sections for optical examination. The extinction is nearly straight, but, in the larger grains, is not very perfect owing to strong dispersion. The elongation is negative, but the mineral is too opaque to yield figures in convergent light. It is probably arfvedsonite and belongs certainly to an older generation than the ophitic patches of riebeckite above described.

iii. Prisms and patches of a somewhat pleochroic brown to yellow mineral, possibly cossyrite. This sometimes forms the centre of a thin prism, the outer zones of which consist of the green-brown mineral (arfvedsonite ?).

Phenocrysts of quartz (1 mm.) and of sligtly decomposed orthoclase (2 mm.) are not very abundant. There is a good deal of haematite staining throughout the rock.

*Summit of Mount Greville.*—A very similar rock to the last, but decidedly more trachytic in character, the felspars

being more lath-shaped. The cossyrite (?) is much darker than in the rock from the base, probably owing to separation of haematite. In both rocks the amphibole is the last mineral to crystallize, enclosing quite idiomorphic quartz.

*Great dyke on Mount Alford.*—The rock has an extremely fine grained base of lath-shaped orthoclase, considerably decomposed, with a little interstitial quartz. Here and there a spherulitic structure is suggested. There are very occasional phenocrysts of quartz and thoroughly glassy sanidine.

*Devitrified obsidian, Mount Alford (not in situ).*—An extremely fine grained rock consisting of a colourless base crowded with green needles. The base consists of a mosaic of untwinned orthoclase, having all the appearance of having been formed by the devitrification of a glass with the composition of a felspar. The green fibres are long but excessively thin, strongly pleochroic brownish-green .to opaque, and with straight extinction ; they are probably ægirine. Their arrangement is variolitic, with occasional bunches in which the fibres are more radially arranged.

*Obsidian, Mount Alford (not in situ).*—Vitrophyric rock. The base consists of nearly colourless glass, very clear and free from crystallites or other elementary forms. The glass is slightly perlitic, but this structure is very imperfectly developed. There are abundant phenocrysts of clear fresh felspar very sharply idiomorphic. Some of the sections are broad, suggesting a tabular habit, others are rhomb shaped as if the mineral were prismatic. Mostly the sections are untwinned or twinned after the Carlsbad law, but here and there very hazy *moirée* structure can be seen. The refractive index is less than that of Canada balsam. The felspar is probably anorthoclase. These phenocrysts contain inclusions in the form of very striking negative crystals filled with glass.

*Pitchstone, Spicer's Gap.*—A nearly colourless glass, crowded with minute microlites of felspar in the form of excessively thin idiomorphic plates. Sometimes these are arranged one above the other in sets of three, with the axes of the three plates inclined to one another. At other times they have a kind of *echelon* formation. These overlaps give the appearance of twinning but the plates are really simple.

There are a very few larger phenocrysts of sanidine, idiomorphic and twinned after the Carlsbad law and somewhat corroded by the base.

*Olivine-basalt, near the summit of Mount Mitchell.*—The base is pilotaxitic with a very marked flow structure. It consists of plagioclase, augite, magnetite, ilmenite, and apatite.

The plagioclase is labradorite ($Ab_9$ $An_{11}$) in lath shaped crystals up to 0·5 mm. in length, twinned after Carlsbad and albite laws.

Augite is purplish and faintly pleochroic from brown to purple and is ophitically arranged.

Magnetite in small octahedra and ilmenite in thin plates appear to be quite independent of one another. There is a good deal of dark green chlorite throughout the slide, also large quantities of apatite in very fine needles.

Olivine is fairly abundant in idiomorphic crystals up to 1 mm. by 0·5 mm., much altered to dark green fibrous serpentine. A few irregular cavities are filled with analcite.

*Coarse olivine-basalt, South-east corner of Portion 121, Parish Clumber (near the base of Mount Mitchell.*—Coarsely pilotaxitic in structure. Two generations of plagioclase are present. The individuals of the first set are large prismatic crystals with square cross sections and reach 4 mm. by 0·5 mm. They consist of labradorite $Ab_3$ $An_4$ and

are quite fresh and twinned after the Carlsbad and Albite laws. The felspars of the second generation differ only in size, ranging about 0·5 mm. by 0·1 mm.

Olivine is remarkable as occurring in *two distinct generations*, a phenomenon quite unusual for this mineral. The earlier formed crystals are magnificent idiomorphic forms, 3 mm. by 2 mm., with notably good cleavages. Along the cracks there is a good deal of alteration into serpentine, the fibres standing at right angles to the cracks. Another remarkable feature about these large olivines is that peripherally they are moulded on the felspars of the second generation. The olivines of the base are of small dimensions and almost completely serpentinized.

Augite is in brownish-grey grains and imperfect prisms 0·2 mm. long. It is entirely interstitial in character but is not ophitic (granulitic according to Judd).

Ilmenite occurs in plates and irregular grains enclosing felspars but themselves moulded by augite. Also enclosed in olivine and augite are a few octahedra of magnetite, but most of the iron ore of the rock has the irregular habit of ilmenite.

There is much apatite in thin needles of a faint but decided greenish tint. This is enclosed in all the felspars, but not a single example of its inclusion in olivine was noted. The abundant chlorite is distributed in such a way as to suggest the infilling of numerous microlitic spaces. There is a good deal of zeolite filling small irregular spaces. It is of two kinds, (i.) cloudy brown almost opaque material which is indeterminate, and (ii.) a clear fibrous mineral answering to stilbite.

*Quartz syenite, Mumbilla-Engelburg Road.*—Hypidiomorphic granular rock of rather variable grainsize. The most abundant mineral is anorthoclase in prismatic sections. It is perfectly fresh and is simple, shows twinning after

the Carlsbad law. The refractive index is always less than that of Canada balsam or quartz, and the symmetrical extinctions of the two halves of the Carlsbad twins give readings of 9°. On untwinned sections the extinction is + 10°. In addition to this dominant felspar there is a small quantity of oligoclase in subidiomorphic sections with well marked peripheral outgrowths of anorthoclase in crystal continuity. Quartz is not abundant, it occurs interstitially in irregular grains.

The coloured constituents are subordinate in amount. Augite is in stout prisms, greenish-brown in colour, averaging about 0·2 mm. by 0·1 mm., but very many are much more slender. These have a peripheral border of dark green hornblende and very frequently quite considerable terminal extensions of the same mineral. This latter occurs also in independent crystals but not abundantly.

Scattered through the slide are ragged and subidiomorphic flakes of exceptionally dark brown biotite. The vibrations at right angles to the cleavage give a dark brown colour, those parallel to the cleavage are completely absorbed. There are plentiful thin flakes of ilmenite up to 0·2 mm. by 0·01 mm. Apatite is exceptionally abundant in excessively thin needles up to 0·3 mm. In some of the felspar crystals there is a perfect tangle of such fibres. The order of consolidation is as follows :—

Apatite
Augite
Plagioclase
Hornblende
Anorthoclase
Biotite
Ilmenite
Quartz

*Olivine basalt, Summit of Mount Mitchell.*—The rock is hyalopilitic. The great bulk of it is made up of minute singly twinned felspar microlites with very perfect fluidal arrangement. At first sight these appear to be sanidine, as their extinction is almost straight, and there are no albite lamellæ visible. The refractive index however is greater than that of cooked Canada balsam, so that the mineral is oligoclase. There is very plentiful magnetite in minute idiomorphic crystals.

Much less abundant is augite in yellowish-grey subidiomorphic grains, interstitial between the felspar laths. A little ilmenite in very thin plates can be made out.

There is quite abundant interstitial glass, brown to brownish-green in colour and quite isotropic.

Scattered small crystals of olivine up to 0·5 by 0·2 mm. give the rock a porphyritic appearance on a small scale.

A very few plagioclase crystals of the same order of size also occur. Some of these are untwinned and look extremly like nepheline, but yield a biaxial figure in convergent light.

Some of the magnetite grains rise to porphyritic dimensions.

Rounded masses of small size of fibrous secondary material occur, apparently natrolite.

*Porphyritic olivine basalt, Summit of Spicer's Peak.*—The rock has a pilotaxitic base of oligoclase microlites, tiny octahedra of magnetite, needles of augite and small pseudomorphs of serpentine after olivine. The arrangement is strongly fluidal; no glass is present.

Scattered phenocrysts of acid labradorite up to 5 mm. by 2 mm. occur. These are very clear and free from decomposition and show perfect examples of Carlsbad, albite and pericline twinning. They contain fairly abundant inclusions of augite granules and long subparallel streaks

of a colourless mineral with low refractive index and weak double refraction. This is probably another felspar intergrown with that of the large crystal, but the material was insufficient for precise determination.

Quite scarce are pseudomorphs of brown serpentine after olivine. The shape and internal structure of the original are preserved.

The secondary material is strongly pleochroic, and its double refraction is quite strong for serpentine.

There is much apatite in tiny needles. Small spaces, up to 1 mm. in diameter, mostly quite irregular in shape are filled with zeolites, some with analcite, some with stilbite.

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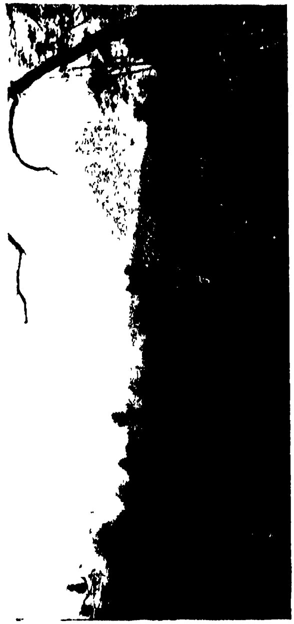
Sp g a



nnngb Gap

Moun m Old Warw

# PRELIMINARY NOTE ON THE GEOLOGY OF THE KEMPSEY DISTRICT.

By W. G. WOOLNOUGH, D.Sc., F.G.S., Lecturer in Applied Geology and Mineralogy, University of Sydney.

[With Plate V.]

[*Read before the Royal Society of N. S. Wales, August 2, 1911.*]

THE author hopes to have an opportunity, in the very near future, of spending sufficient time in the field on the Macleay and Manning Rivers to enable him to lay before the Royal Society a fairly complete account of their geological history. The results obtained during a brief visit in January and February of this year seem, however, of sufficient interest and importance to justify an immediate statement, which may serve as a guide to other observers should it be impossible for the author to carry out his intended investigation.

**Geology of the Macleay River Area.**

Approaching Kempsey from the New England Tableland viâ Armidale, the dominant formation met with on the Upper Macleay is an intensely jointed slate. No fossils have been met with in this slate series, so the age is uncertain. The dips are at very high angles; and jointing in several directions, also steeply inclined to the horizontal, splits the slates into long prismatic pieces like large slate pencils. These rocks may be as old as Silurian, to which system they were referred by Clarke. Bands of conglomerate occur at intervals, (as *e.g.*, near Bellbrook) and may be of value as a clue to the age of the beds, and as persistent horizons for working out their distribution.

These Silurian (?) rocks are strongly intruded by a mass of biotite granite, extensively developed near the junction of George's Creek and the Macleay.

At Anderson's Peak near Bellbrook, there occurs a capping of basalt some hundreds of feet in thickness resting upon an isolated peak composed of slates.

On the east, the Silurian rocks are bounded by a series of contorted and cleaved quartzites and slates which we may refer to as the Kempsey slates. The boundary appears to be near Hickey's Creek, where a heavy conglomerate is met with. In the road sections between Hickey's Creek and Kempsey, the slaty rocks exhibit dips in all directions and there does not seem to be any well defined axis of folding.

On the coast between Smoky Cape and South West Rocks, what appear to be the equivalents of the Kempsey slates occur in broad undulations but with an approximately horizontal disposition as a whole. They are black in colour and intensely hard, as the result of contact metamorphism. This effect is produced by two masses of intrusive rock. The bold promontory of Smoky Cape consists of a porphyrite

of most handsome appearance; the groundmass is light grey, and through it are scattered very abundant phenocrysts of white felspar up to one-third of an inch diameter and less conspicuous crystals of dark hornblende. When polished it should make one of the most beautiful building stones imaginable.

Connected with this mass are numerous sills of light-coloured, fine-grained felsitic rock, intruding the black sediments lying to the north of the Cape. At Arakoon there is a small boss of granite whose junction with the dark sedimentary rocks to the south of it is a very conspicuous feature in the cliff section. The granite varies from grey to pink, the latter colour being produced by an abundance of large idiomorphic, flesh-coloured, crystals of orthoclase. In the quarry face at the Trial Bay Prison the granite is seen to be crowded with large angular blocks of intensely altered sedimentary rock, and, as the junction line is approached, these masses become larger and more numerous till they attain dimensions up to 40 feet in length. The granite mass is quite a small one and does not extend as far as South West Rocks where the slaty rocks again put in an appearance. At the New Entrance to the Macleay the quarries for materials for the breakwater expose a remarkable conglomerate. In general appearance and in the sporadic distribution of its pebbles it suggests a glacial till, but I have no distinct evidence for or against such an idea. Between this isolated mass of highland and Kempsey stretch the alluvials and swamps of the Lower Macleay.

Another coastal headland further south, Crescent Head, deserves mention. The headland itself consists of greyish shales and sandstones dipping in a northerly direction.

During the time at my disposal I searched for fossils but found only undeterminable plant remains, probably *Equisetaceæ* of some kind.

About two miles inland from Crescent Head, and separated from it by a belt of swampy land, is a steep escarpment consisting of very massive conglomerates. The form of the escarpment is very strongly suggestive of a fault parallel to the coast. The lithological character of the conglomerate is similar to that of the rocks of Camden Haven, which have been determined by Carne as Trias-Jura. The conglomerate extends inland for a considerable distance, but is mostly hidden by the marshy alluvials which are so strongly developed in this area.

On the southern side of the Macleay River above Kempsey there occur rocks of very great importance from the point of view of Australian stratigraphy, and it is to these I wish to direct attention especially.

Crossing the river at Sherwood we come almost immediately upon conglomerates interstratified with the Kempsey slates, but in this neighbourhood their relationships are not at all clearly defined.

Following the road to Moparrabah and Willi Willi, in a general west-north-westerly direction, an extensive series of chocolate and olive-green crumbly shales are encountered. These have a fairly uniform dip of N. 30° W. at 15°.

At Portion 109, Parish Kullatine, a massive belt of crinoidal limestone crosses the track, but the rocks immediately associated with it are not exposed. Inclusive of the occurrence just noted, the track crosses similar belts of limestone three times between this point and Moparrabah. In each instance the beds seem to be passed in descending sequence, though this is not certain. There may be several bands of limestone, or lenticular masses of this rock upon different horizons, or one and the same band may have been displaced by a series of step faults, throwing in a general easterly direction. Which of these explanations is the correct one must be decided by detailed mapping of

the district; at present I am inclined to favour the idea of dislocation of a single bed by faulting. The limestone belt extends more or less continuously in a general E.S.E. to W.N.W. direction for upwards of 22 miles, and may be even more extensive inland. At various points limestone caves are developed, as at Yessabah, Moparrabah and Sebastopol. None of those examined by me are of great extent or conspicuous beauty, but I was informed that some of the caverns to the west of Sebastopol are finer than any of those I saw. In one place on Tait's Creek there is said to be a fine natural bridge across the valley.

The most extensive development of limestone is at Sebastopol, where a magnificent escarpment of this rock rises about 1,000 feet above the valley of Tait's Creek. The main mass of limestone is about 250 feet in thickness, and forms a vertical wall of cliff at the summit of the steep slope above mentioned. The rock is very dense and somewhat crystalline, but an abundant and fairly well preserved fauna has been obtained from it, proving its age to be Permo-Carboniferous. The facies of the fauna suggests that the horizon of the limestones here may be the same as that of the limestones at Pokolbin in the type district of the Hunter River. The bed dips N. 10° W. at 25° to 28° and the slope in that direction from the summit of the cliff is fairly gradual.

Towards its base the massive limestone reef passes into flaggy argillaceous limestone and this into chocolate and blue calcareous shales, which support a dense subtropical "brush" on the southern side of Sebastopol. This "brush" hides the continuation of the section at this spot, but in the clearer timbered country to the east it is found that the shales pass downwards into chocolate mudstones strikingly like those of Lochinvar on the Hunter, and, like the latter, containing numerous erratics, some of which are of

considerable size. Some of these are distinctly glaciated and no doubt, a careful search would reveal many such.

At Stony Creek, about Portion 156, Parish Kullatine, the road cutting exposes a splendid section of the same formation. Here the chocolate groundmass is crowded with sharply angular rock fragments, mostly of small size, but contains abundant large erratics, scattered through it, singly or in groups. These erratics consist mostly of granites and reddish quartzites, and do not, so far as I have observed, show any examples of the hard tuff to be described presently. One of the erratics from this locality, a boulder of quartzite about 12 inches long by 8 inches in diameter is beautifully glaciated. This occurrence of till lies in the same position with respect to the limestone belt as that at Sebastopol.

There can be no reasonable doubt that we are here dealing with a new and very extensive development of the Lochinvar Glacial Beds of the Hunter Valley, described by Professor David.[1] In the type district these Glacial Beds form the base of the Permo-Carboniferous System, and rest unconformably on Rhacopteris Beds belonging to the Carboniferous System.

The great interest and importance of the Upper Macleay Permo-Carboniferous is that the Glacial Beds do not appear to be the basal beds of the system, but seem to be underlain by a great, but at present undetermined, thickness of conformably bedded tuffs. In Parabel Creek these dip N. 10° W. at 25°. The continuity of the section is not all that could be desired, as the wide valley of Parabel Creek intervenes between the Glacial Beds and the nearest outcrop of the tuff to the south, but the first beds of the latter which are met with in that direction conform pretty closely

[1] Discovery of Glaciated Boulders at Base of Permo-Carboniferous System, Lochinvar, N.S.W., Prof. T. W. E. David, this Journal, Vol. XXXIII.

in direction and amount of dip to the definite Permo-Carboniferous sediments. As already stated, the latter are by no means uniform in their dip and the divergence between the inclinations of the tuff and the limestones is not so great as the differences found in the dip of the latter. While this slight element of doubt as to the continuity of the section exists with respect to the Moparrabah area, a comparison with the Manning River formations to be described later, throws the balance of probability strongly in favour of conformity of the entire series. At the time of my visit Parabel Creek was in heavy flood, so that the measurement of the section could not be continued southwards, but even within that portion examined, a very considerable thickness of sub-glacial tuffaceous beds is revealed.

These rocks vary from bluish fine grained flaggy beds to coarse tuffaceous sandstones of a greenish or purplish colour.

Section along B on map

Sebastopol

Taits Creek

McCoys Ck.

Parrabel Creek

B

SE

Between the Macleay and Manning Rivers no detailed examination was attempted, though the formations developed and the relationships between them are of very great interest and importance.

On the Manning River several excursions were taken with Taree as a centre, and considerable collections of rocks were made by enthusiastic residents.

About two miles east of Taree a thick bed of limestone dipping N.E. at 43° crosses the main road. At this point the limestone is bluish-grey, rather crystalline, and contains no fossils except a few crinoid stems. What appears to be the same bed of limestone was picked up at intervals for a distance of about seven miles, in a general west-north-westerly direction to a point near Wingham. At the Taree Rifle Range the limestone is dark greyish-brown and distinctly oolitic. At Ahearn's (five miles from Taree on the Cedar Party Creek Road) it passes into a handsome reddish marble, while at Wingham it is a greenish crystalline limestone. At Ahearn's there are numerous pebbles of slaty and schistose rock up to four inches diameter, embedded in the limestone in a way which suggests the "dumping" of small erratics by icebergs. At Wingham well preserved specimens of large *Aviculopectens* occur, indicating that the bed is of the same age as, and probably identical with, the limestone of the Macleay River.

No very decisive evidence of the existence of the Lochinvar glacials on the Manning has been obtained so far. A strong bed of conglomerate occurs below the limestone at Taree in the correct position for the glacial bed, but I was unable to satisfy myself definitely as to its glacial character. At Ahearn's, immediately below the limestone there is a bluish gritty bed, almost a breccia in places, but here again no very conclusive proof of glacial origin is forthcoming.

Stratigraphically below the limestone, and undoubtedly conformable with them there is an immense series of greenish tuffs and tuffaceous slates, considerably contorted and faulted, so that its exact thickness cannot be estimated at present. This series is closely similar in lithological character to the sub-glacial tuff of the Macleay River, and I feel quite confident as to the identity of the two formations. A very important fact is that certain horizons (or a certain horizon) in the Manning area is richly fossiliferous. In the railway ballast quarry at the Devil's Elbow (about five miles along the line from Taree towards Wingham) there is exposed a massive bed of greenish tuff which contains abundant casts of *Pachydomus*, which Mr. Dun recognises as being very similar to a form occurring in the Gympie Series at Gympie in Queensland. Very numerous specimens of this fossil are to be obtained from the railway ballast derived from this quarry. What is probably the same bed occurs in a railway cutting west of Kiliwarra Railway Station, and here again *Pachydomus* is abundant. If these two occurrences are parts of one bed it should provide a most useful persistent horizon in geologically mapping the district.

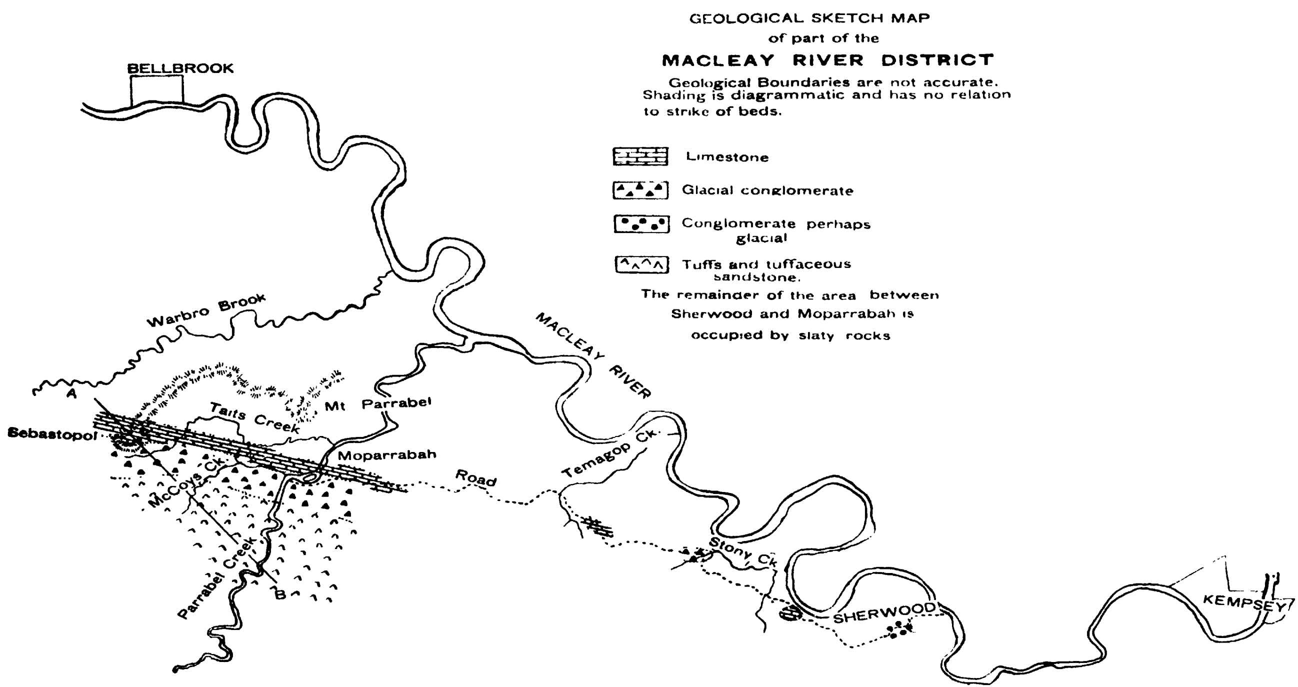
The discovery of this fossil determines the age of the beds as Permo-Carboniferous, and, taken in conjunction with the evidence of the Macleay beds, indicates a vast thickness of subglacial beds of that age. A comparison of the lithological characters of this subglacial tuffaceous series, with those of the gold bearing rocks of Gympie itself, shows a very striking similarity between the two formations, and I venture to suggest that we may tentatively assume, as a working hypothesis, that the Gympie System of the Queensland geologists includes the subglacial portions of the Manning and Macleay beds. If this is so, a detailed survey of the areas described in this note is likely

to clear up many of the points which now present difficulties in correlating the geological formations of New South Wales and Queensland.

Rocks of undoubted Carboniferous age occur in the Manning River area. At Crowdy Head are tuffaceous rocks, not essentially different lithologically from the subglacial tuff above referred to. But while the latter beds dip mostly northerly or north-easterly, the Crowdy Head beds dip southerly, this suggests an unconformity. The presence in the Crowdy Head beds of *Knorria* and very abundant plant impressions indicates their Carboniferous affinities. The Cape Hawke beds, to be described in a paper by Messrs. Briggs and Watson, conform in direction of dip to the Crowdy Head beds. Between Krambach and Gloucester the dips are mostly southerly, and at Copeland, where lithologically similar beds are developed, *Lepidodendron* has been met with.[1] The correlation of the *Lepidodendron* beds with those containing *Pachydomus* is a work of first rate importance in Australian stratigraphy, and it is the intention of the author to endeavour to carry out this work in the near future.

My thanks are due to the many residents of the Kempsey, Taree and Gloucester districts who assisted me by advice, hospitality and transport. I wish to express my gratitude also to Messrs. Briggs and Watson, students at the Sydney University, for their loyal and unselfish assistance under far from pleasant conditions of field work. Professor David and Mr. Dun have been ever ready with advice and help at all points, and to them my best thanks are gratefully rendered.

[1] Ann. Rep. Dept. of Mines for 1889, p. 230, and Min. Prod. N.S. Wales 1887, p. 60.


GEOLOGICAL SKETCH MAP
of part of the
MACLEAY RIVER DISTRICT
Geological Boundaries are not accurate.
Shading is diagrammatic and has no relation
to strike of beds.
Limestone
Glacial conglomerate
Conglomerate perhaps glacial
Tuffs and tuffaceous sandstone.
The remainder of the area between
Sherwood and Moparrabah is
occupied by slaty rocks
BELLBROOK
Warbro Brook
A
Sebastopol
Taits Creek
Mt Parrabel
Moparrabah
McCoys Ck
Parrabel Creek
B
Road
MACLEAY RIVER
Temagop Ck
Stony Ck
SHERWOOD
KEMPSEY

*Reprint from Medical Journal of Australia,*
*October 31, 1914.*

# The Detection of Albumin in Human Urine.

By H. G. Chapman, M.D., B.S. (Melb.),
(From the Physiological Laboratory of the University of Sydney.)

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The term albumin is used by physicians to denote certain proteins that appear in the urine of some persons. The urine of healthy persons does not contain albumin except for brief periods following severe exertion, and under other exceptionable circumstances. In the urine of some persons albumin may be present without any other signs of disease of the kidneys. This constitutes the condition known as physiological albuminuria.

The presence of albumin in urine can be detected by tests which fail to reveal any albumin in the urine of most healthy persons. The presence of protein can be demonstrated in urine provided that special methods involving concentration of the urine be employed. The problem of detecting these traces of protein in large quantities of urine must be distinguished from that of detecting albumin in small amounts of urine. The detection of albumin in small quantities of urine is the theme of this paper.

Many tests have been employed to reveal the presence of albumin in urine, but no single test is so free from fallacy that dependence can be placed upon it in every case. I propose to place before you the methods that have been used by me for some years. In order to detect the failure of single tests to show the reaction for albumin in urine I have employed four different ways of testing every sample coming under my notice. For some years I used a fifth test, but as it yielded so frequently results at variance with those obtained by other methods, I have ceased to employ it, and to recommend its use to students. The tests have been applied to the urine in this order:—

(1) The boiling test.

(2) Heller's nitric acid test.

(3) The test by precipitation with salicyl-sulphonic acid; and

(4) The test by precipitation with hydro-ferrocyanic acid.

The fifth test, formerly used by me, was that of precipitation by picric acid, or by Esbach's reagent.

The art of applying these tests may be considered under the following headings:—

Choice of the sample of urine.—It is preferable to use for the tests portions of the mixed urine of 24 hours. The most generally useful sample of the urine for 24 hours is that of the urine passed in the day plus the quantity passed during the following night. The amount of urine obtained in this way corresponds to the food and drink taken by the patient on the day the collection is started. The particular hour at which the collection is begun should be decided by the habits of the patient. A patient awakens and rises at 7 p.m.; urine is passed, and the time of micturition is noted. The urine passed subsequently in the day is kept. The urine passed during the night, if any, and that voided at the corresponding hour on the next morning are added to complete the specimen for 24 hours. Provided the patient is warned to pass water before defæcation, little urine will be lost, and a tolerably accurate estimation of the total quantity of urine for 24 hours will be obtained.

The urine should be kept in vessels which have been washed with soap and water and scalded with boiling water before use. Preserved in such vessels urine remains unchanged a sufficient time for the clinical chemical examination, unless it has already undergone decomposition in the bladder. In hospitals and institutions where the same vessels are continuously used to hold urine these vessels should be sterilized in steam each day. The whole of the quantities of urine passed at different times may be mixed together except when it is needed to examine separately the morning urine, the evening urine, that passed after special work, or that voided after occupying some special posture. The urine should be mixed thoroughly by inverting the vessel or by

stirring carefully. The formation of froth in this procedure must be avoided.

For many purposes it is unnecessary to collect the sample of 24 hours, and a portion of urine voided at any time may be used.

Clarification of the urine.—Accurate tests for albumin are only possible when the urine is clear, bright and free from opacity. Samples kept in clean vessels remain free from bacterial growth, and do not become cloudy from the presence of micro-organisms before examination. Turbidity due to the presence of amorphous urates and phosphates, crystalline substances, blood and formed elements can be removed by filtration through paper. The physician will find it valuable to employ the papers made by Messrs. Schleicher and Schuell, and labelled No. 589, white label. These papers should be moistened with water on the funnel before use as filters. If necessary two papers may be employed as a doubled filter, and the urine repeatedly filtered through the same filter. Occasionally the examination of old or decomposed urine is required. If possible a fresh specimen should be obtained. If this cannot be done, the urine must be cleared as far as possible by filtration. It is difficult to clarify urine opaque from the presence of bacteria. The addition of a little barium carbonate, kaolin, or powdered glass, agitation and subsequent filtration will be found beneficial in some cases, though this treatment may remove some albumin. The addition of a few drops of potash, which throws down the phosphates of the alkaline earth metals, serves to form a flocculent precipitate which mechanically carries down bacteria. The urine is filtered, and then treated with an amount of acetic acid equivalent to the alkali employed. In these ways urine may be cleared before carrying out the tests.

Cleanliness of apparatus.—The test tubes and pipettes used in testing for albumin must be scrupulously cleaned. It is difficult to free glass apparatus from albumin once it has dried on the glass. Thorough washing even with soap often fails to remove the last trace of this dried albumin. It will, therefore, be found advantageous to clean all pipettes and test-tubes immediately after use. This

is preferable to an attempt to clean them on each occasion before use. Pipettes are easily kept clean by washing them in cold tap-water after each occasion when they are used. Test-tubes may be kept fit for use by washing them with cold water several times under the tap, then giving them a scrub with a test tube brush with a little soap on it, and rinsing three or four times under the tap. They should be stood inverted in the rack.

The reaction to litmus.—Most urines give the amphoteric reaction, turning sensitive blue litmus paper red and red litmus paper blue. The reaction is accurately determined by placing with a glass rod a drop of urine on the dry paper, and shaking it off after 20 seconds. Some urines react acid. Such urines are usually dark-coloured and of high specific gravity. Other urines react alkaline. The latter urines contain alkaline carbonates, and effervesce on the addition of dilute acetic acid. They must be rendered faintly acid by the addition of acetic acid precedent to testing for albumin. After the administration of citrates, acetates, tartrates and carbonates, the urine contains much carbonate, and the addition of a few drops of strong acetic acid (40 per cent.) may with advantage precede the use of dilute acetic acid (2 per cent). When the urine has decomposed with the formation of ammonium carbonate from urea, the same procedure may be employed. Unless the alkaline urines are accurately neutralized, fallacious results are readily obtained on applying the tests for albumin.

The specific gravity.—It is a good practice to take the specific gravity of the urine at the commencement of the routine examination of urine. This is done by floating a urinometer in the urine, and reading off the mark on the stem opposite the lower level of the meniscus of the superficial layer. This is thus read through the urine, the eye being at the level of the surface. This is sufficiently accurate for most purposes, though the reading should be made at 15.5 deg. C. (60 deg. F.). A large correction is necessary when the urines are tested at or near 35 deg. C., as may happen with specimens taken in cases for insurance. High specific gravities suggest the possi bility of certain fallacies in some of the tests.

The boiling test.—About three inches of urine are introduced into a test tube. One drop of 10 per cent. acetic acid is added to any urine not acid in reaction to litmus, and the contents of the tube mixed by inversion. The upper inch of the urine is heated in a small flame, the test tube being held at the bottom. The heat should be applied gradually until the fluid boils. The dilute acetic acid (10 per cent.) is then added drop by drop to the hot urine. A persistent cloud shows the presence of albumin. A cloud may appear on boiling, due to the precipitation phosphates of the alkaline earth metals, but this cloud dissolves on the addition of acetic acid. When much albumin is present the cloud is replaced by a flocculent precipitate. This precipitate may be so considerable that the urine became solid. Five to ten drops of acetic acid may be added to the hot urine when a cloud is present, as there is no possibility of the solution of coagulated protein. When no cloud is present on boiling the acetic acid is added drop by drop, waiting five seconds between each addition of the acid until five drops have been added, the course of each drop through the urine being observed. If a cloud is formed in the path of the drop the further addition of acid should be performed very slowly. When the test is performed in this way, a faint cloud is readily observed by its contrast with the clear transparent urine below, especially against a dark background. Clouds may be also obtained due to the presence of mucin and nucleoprotein.

Heller's nitric acid test.—About one inch of pure colourless concentrated nitric acid is placed in a test tube. Five cubic centimetres of urine are drawn up in a pipette. The test tube is held inclined to the horizontal until the nitric acid reaches half way up the test tube. The pipette is held nearly horizontal, and the urine allowed to run slowly down the glass on to the urine. The line of junction between the acid and urine is examined. A white cloud at the line of junction indicates albumin. It is advisable to allow the test tube to stand for 30 minutes before drawing a negative conclusion. Care must be taken not to confuse coloured rings with the clouds. Similar clouds appear due to mucin and nucleopro-

tein. A cloud may appear from copaiba resin. Clouds formed above the line of junction may be due to urea nitrate or urates. The urea nitrate is, however, crystalline. When there is any doubt as to the nature of a cloud the urine should be diluted with an equal volume of water, and the test repeated. Urea and urates give clouds only in highly concentrated urine. The cloud due to resin of copaiba is soluble in alcohol.

Precipitation with salicyl-sulphonic acid.—This test was introduced by McWilliam. (1) The reagent is used in a saturated aqueous solution. Five drops of the solution are added to a test tube three-fourths filled with urine and mixed by inversion. The urine shows a flocculent precipitate, a cloud or an opalescence according to the amount of protein present. Any urine not alkaline in reaction yielding no opalescence with this reagent is free from albumin. Precipitates may form with mucin, nucleoprotein, and many other substances.

Precipitation with hydroferrocyanic acid.—One inch of urine is mixed with an equal quantity of 8 p.c. aqueous solution of potassium ferro-cyanide. A 10 per cent. solution of acetic acid is added drop by drop. A fine white precipitate is produced in the presence of albumin. Mucin is not precipitated but nucleoprotein may be. The test is rarely fallacious from precipitation of other bodies than protein.

Relative delicacy of the tests.—A urine yielding no positive reaction with any of the above tests is mixed with human blood serum. The amount of protein in the serum is estimated gravimetrically, so that it is possible to measure accurately the dilution of the protein in the urine. As this takes time, the serum is diluted with urine, and the exact figures obtained when the albumin in the serum has been estimated. Care must be taken that the temperature of the urine is 15 deg. C. The dilutions are made with considerable quantities of the serum diluted with urine, at least 50 c.cm. being diluted each time. A series of dilutions of orders of magnitude, 1 in 20,000, 1 in 25,000, 1 in 30,000, 1 in 100,000, 1 in

500,000, and 1 in 1,000,000 are made. Some results are shown in the table:—

| Dilution of albumin. | Boiling test. | Nitric acid test. | Salicyl-sulphonic acid test. | Hydro-ferrocyanic acid test. |
|---|---|---|---|---|
| 1 in 20,000 .. | + | + | + | + |
| 1 in 25,000 .. | + | ? | + | + |
| 1 in 30,000 .. | + | — | + | + |
| 1 in 100,000 .. | + | — | + | + |
| 1 in 500,000 .. | + | — | + | ? |
| 1 in 1,000,000 .. | ? | — | ? | — |
| No albumin .. | — | — | — | — |

+ = positive reaction when the test is carried out as described supra.
— = negative reaction when the test is carried out as described supra.
? = reaction has been sometimes positive and sometimes negative.
The quantities of albumin represent parts by weight of dried protein in parts by volume of the urine.

It will be seen that the tests vary greatly in delicacy.

The cold nitric acid test is much less sensitive than the others. It yields a positive result with a urine containing 1 part of albumin in 20,000 of urine. It yields a negative result with a urine containing 1 part of albumin in 30,000 of urine. It is only possible to detect 1 part in 25,000 in some urines. Two tests are exceedingly sensitive, belonging to the series of the most sensitive chemical tests known. These tests are the boiling test and salicyl-sulphonic acid test. They detect 1 part of albumin in 500,000 of urine with certainty, and sometimes 1 part in 1,000,000 of urine. The hydroferrocyanic acid test always detects 1 part of albumin in 100,000 of urine, and rarely 1 part in 500,000 of urine.

These results have been obtained by me two or three times a year during the last ten years. They have been checked by some hundreds of students. As different urines and different albumin must be used on each occasion it appears probable that they give the limits of accuracy of these tests with some correctness. In the table the actual figures have been rounded off.

As the 24-hour sample of urine in this country does not often exceed 1 litre, the nitric acid test detects the presence of 50 milligrams of dried pro-

tein in 1 litre of urine. This is equivalent to an admixture of 1 c.cm. of blood serum to the litre. The hydroferrocyanic acid test detects an admixture of 0.2 c.cm. of blood serum, and the salicylsulphonic acid and boiling tests an admixture of 0.04 c.cm. in the litre. In this way it is possible to determine how much serum has passed the kidney in any case. Figures like these also give data to form a judgement as to whether the albumin present in a case is due to the inclusion of cellular elements or to the entrance of proteins from the blood.

The presence of nucleoprotein.—Certain writers distinguish between nucleoprotein and albumin. I have invariably found that albumin accompanies nucleoprotein in urine. For clinical purposes nucleoprotein may be regarded as albumin. Nucleoprotein may be distinguished from the other proteins found in urine by its precipitation with dilute acetic acid in the cold. The test is conveniently carried out as a ring test.

It is now possible to discuss the use of these four tests. It may be granted that they are all of sufficient delicacy with the possible exception of the nitric acid test, which might fail to show a minute trace of albumin in the earliest stages of Bright's disease. The difficulties in their use are due to fallacies caused by the presence of drugs and the products of the oxidation of certain foods in the urine. These complicate some tests more than others. The use of several tests guards against error in applying any single test. It may be safely accepted (1) that any urine giving a negative result with the salicylsulphonic acid test is free from albumin, (2) that any urine yielding positive results with the four tests contains albumin, (3) that any urine yielding a negative result with the hydroferrocyanic acid test and faint positive results with the other three tests contains mucin, but not albumin*, and (4) that any urine yielding a negative result with the cold nitric acid test, and faint positive results with the other three tests, contains a trace of albumin.

## REFERENCE.

(1) "British Med. Journal," 1891, vol. 1, 837, and 1892, vol. 2, 115.

* Such a urine yields a precipitate with dilute acetic acid in cold.

Shipping Newspapers Limited, 16 Bond-st., Sydney.

# NOTE ON THE ESTIMATION OF FAT IN FOOD FOR INFANTS.

By H. G. CHAPMAN, M.D.
(From the Laboratory of Physiology in the University of Sydney.)

[*Read before the Royal Society of N. S. Wales, December 2, 1914.*]

RECENTLY I analysed a food prepared for infants. The estimation of the fat led me into serious error. Special investigation was needed to obtain an accurate result. The composition of the food is indicated from the following data. It contained 2·25% of water. The quantity of nitrogen was 2·8% (2·79 and 2·81), of which 0·25% represented non-protein nitrogen. The percentage of ash was 3·55 (3·557 and 3·553). About 60% of the food consisted of carbohydrate of which about one-sixth was insoluble in alcohol (dextrins). At 45° C., 72·9% of the food dissolved in water and 67·6% was dissolved by boiling water so that 5·3% of protein was soluble at 45° C.

An attempt to estimate the fat was made by placing the dried powder in a thimble into a Soxhlet's apparatus and extracting it with dried ether free from alcohol. The results are given in Table I.

Table I.

| No. | Weight of Dried Food in gms. | Weight of Fat extracted in gms. | Percentage of Food. |
|---|---|---|---|
| 1 | 0·683 | 0·0514 | 7·40 |
| 2 | 0·7421 | 0·0575 | 7·57 |
| 3 | 0·829 | 0·0636 | 7·50 |
| 4 | 1·5198 | 0·1110 | 7·14 |

In order to be certain that the whole of the fat was extracted, the material was redried and again extracted

for twenty-four hours in the apparatus. Less than one milligram of fat was recovered. Later an extraction was made in a similar way of the contents of six different tins. The averaged result was 7·24% of fat, which agrees sufficiently with the averaged result of the figures in Table I, viz., 7·4%.

An estimation of the amount of fat extracted by petroleum ether was also made in the same way. The estimation gave 6·27% on the first extraction. Redried and extracted a second time, less than 0·02% of fat was obtained.

The fat was estimated also by the Röse-Gottlieb Method.[1]

The results are tabulated in Table II.

Table II.

| No. | Weight of Food in gm. | Percentage of Fat. |
|---|---|---|
| 1 | 1·4915 | 16·67 |
| 2 | 1·8895 | 16·75 |
| 3 | 1·9820 | 16·9 |
| 4 | 2·1660 | 17·0 |
| 5 | 2·6380 | 17·0 |

The figures show an averaged result of 16·85%. This figure is more than twice that obtained by the ordinarily employed method of extraction.

In order to determine whether the fats extracted by the two methods were identical, their saponification numbers were determined by Koettstorfer's process. The numbers obtained were 234 and 236 respectively. Both samples of fat contained a trace of nitrogen (under 0·1%) and yielded no weighable amount of ash on incineration.

To confirm the figures obtained by the wet process of Röse and Gottlieb, a weighed quantity of infants' food was

[1] Aberhalden, Arbeitsmethoden, Bd v., Abt. I, S. 432, Berlin u. Wien, 1911.

placed in a cylinder and mixed with 10 cc. water. The contents of the cylinder were washed on to filter paper, previously extracted with ether. The water was driven off at 90° C. The washing of the traces of undissolved food from the cylinder was a tedious process which occupied about two days. The dried filter paper was extracted with dry ether in a Soxhlet apparatus. The filter paper was redried and the extraction repeated. The results are recorded in Table III.

Table III.

| No. | Weight of Food in gm. | Weight of Fat in gm. | Percentage of Fat. |
|---|---|---|---|
| 1 | 0·7457 | 0·1310 | 17·5 |
| 2 | 1·4785 | 0·2152 | 14·5 |
| 3 | 4·368 | 0·3635 | 8·3 |

It will be seen that the fat is completely extracted when the quantity of food is less than 750 mg. Similar results were obtained by repeating the experiment. An attempt to vary the method by mixing the food with glass wool, moistening with water and drying, yielded only 9.87% of fat. The saponification number of the fat obtained by this method was 232. The fats obtained were thus all butter fats.

To elucidate the failure of the extraction by ether performed in the usual manner, two other foods for infants made by the same firm were subjected to analysis. Both these foods gave the same figures for fats by extraction with ether and by the process of Röse and Gottlieb.

The results are recorded in Table IV.

Table IV.

| No, | Percentage of Fat on extraction. | Percentage of Fat, Röse-Gottlieb. |
|---|---|---|
| 1 | 5·31 | 5·4 |
| 2 | 6·73 | 6·6 |

It is proposed to deal in a later paper with the physical cause of this peculiarity.

I beg to record my indebtedness to Professor Sir Thomas Anderson Stuart, in whose laboratory this research was undertaken, to W. M. Hamlet, Esq., for much valued criticism, to the Nestle and Anglo-Swiss Condensed Milk Company for the opportunity to make these investigations and to Mr. P. N. Woollett for much assistance in the conduct of these analyses.

# Legal Standards for Infants' Foods

— BY —


H. G. CHAPMAN, M.D., B.S.,

[*From the Physiological Laboratory of the University of Sydney.*]



REPRINT FROM

*The Medical Journal of Australia,*

OCTOBER 9, 1915.

# LEGAL STANDARDS FOR INFANTS' FOODS

By H. G. Chapman, M.D., B.S.

*[From the Physiological Laboratory of the University of Sydney.]*

It has been found that infants fed on human milk are more likely to survive than those fed otherwise than from the breast. Not only is the rate of mortality less among breast-fed children than among hand-fed infants, but the incidence of diseased conditions is greater among those fed on foods not derived from human mammary glands. The medical profession has recognized these facts and advocated that the mother should feed her child whenever it is possible. Many mothers are unable to provide sufficient nourishment for their infant, so that it is necessary to supply additional food to the infant. Some mothers do not feed their infants at all, and the children are nourished entirely by what are known as "artificial foods."

It is the custom to regard the method of feeding on the breast as physiological, and to endeavour to approximate to these conditions of feeding when other modes of nourishment are adopted. If the conditions of suckling of infants are examined, attention may be directed to the amount of milk taken by the child at each meal or during each day, and to the composition of this milk. It is only when these data have been ascertained that it will be possible to determine the amount and kind of material that should be supplied in the place of human milk. When search is made for these data, it is remarkable how little information is available in the literature. It should be quite easy with the aid of such a simple instrument as a pair of scales to determine how much milk infants take in each twenty-four hours or at a meal. I have not been able to obtain any data whatever as to the amount of milk taken at any time during the first six months of life by infants born in New South Wales. If recourse be made to data collected in other parts of

the world, it is surprising to find how few measurements have been made. Great variations appear in the results of different investigators. As this matter is of importance to every person in the State, it should be useful to know how much food is taken by a thousand infants during each week of their period of suckling. These figures should then be examined by a simple statistical method to determine whether there is any constancy in the amount taken each day by infants of the same age. As far as I can ascertain, infants do not take less than 400 c.cm. or more than 2,000 c.cm. of milk in the twenty-four hours during the fourth week of their life. This range is so wide that without a sufficient number of figures no very definite conclusions are possible.

The composition of human milk has been examined more frequently than the quantity of the fluid secreted has been measured. In Australia, very few data are available. Mr. Wardlaw has presented us with a series of figures on the amounts of the various components in human milk during the early days of lactation. We require similar series for the milks of mothers at the third, sixth and ninth months of lactation. It may perhaps be necessary to make even more frequent examinations if the composition of milk shows any periodic variations during the course of the lactation.

Mr. Wardlaw's data are of value for computing the composition of milk in the early days of lactation, but his method of examining his results may be applied to other series of analyses of human or animal milk. It is remarkable how few series of analyses of human milk have been made. I have only been able to find four series in which more than fifty samples of human milk have been analysed with the object of obtaining more or less roughly the quantities of the chief constituents, recorded in the literature of the last thirty-five years.

When the simple statistical method used by Mr. Wardlaw is applied to the figures found in the papers recording the results of these series of analyses, they show that the general characters of the results obtained by Mr. Wardlaw are still evident. It becomes apparent that the constituents of human milk may be classified into two groups. The first group includes the solids not fats. These sub-

stances are secreted as the result of a mechanism, which is of such a kind that the amounts of these bodies are approximately constant in all milks. This mechanism, no doubt, is in part similar to that which brings about the approximately constant molecular concentration of the blood serum in all women. The second group includes the fats. The variations in the quantities of fats in human milks show that the mechanism leading to the passage of fat in milk is of such a nature that great variations in the amounts of fats become possible in the milks of different women. It is evident, therefore, that different infants fed on the breast will receive milks with approximately constant concentrations of solids not fat, but with very different concentrations of fats.

It is now advisable to consider the conditions of growth in the infant. The human infant increases in weight slowly. The infant doubles its weight in about 200 days. It weighs 2 to 5 kilos at birth, so that it increases in weight by 2 to 5 kilos in 200 days. This increased weight involves the addition of from 1.3 to 3.3 kilos of water and 0.7 to 1.7 kilos of dry solid matter. It has been pointed out that the infant takes from 400 c.cm. to 2,000 c.cm. of milk each day as food. This contains from 40 gm. to 200 gm. dry solid substance. In 200 days the infant receives from 8 to 40 kilos of solid matter. It is obvious that the infant only uses about one-tenth of its solid food for building its tissues. The remainder of the food is used to heat its body. The infant differs in this way from many animals, in which a greater proportion of the food is used for the formation of the permanent structures of the animal. It has been found that the rate of growth is determined in animals by the character of the various constituents of the food, and especially the kinds of amino acids available in consequence of the digestion of protein. To attain a rapid rate of growth an animal must receive such amino acids in its food, that each of the requisite acids needed for the manufacture of its body proteins is present in sufficient quantity.

The useful infants' foods prepared by manufacturers may be divided into four groups: (1) dried cows' milks, in which the solids of the milk are presented in a finely divided form; (2) dried cows' milks to which additional fat has been added; (3)

mixtures of dried cows' milk, with preparations of various cereals, in which the starch of the grain is more or less completely converted into maltose and glucose; and (4) preparations of cereal grains subjected to various kinds of digestive treatment. It is probable that all these foods have a useful place as substitutes for human milk, but are subject to the limitations already mentioned.

The Acts which are in force in Australia all lay it down that the composition of infants' foods must be such that when prepared as directed for consumption, they shall approximate in composition to human milk. In the administration of these Acts, difficulty has been experienced. Regulations are required to enable the administration of the Acts to be carried out satisfactorily. These regulations set out a standard for the composition of human milk and a certain degree of variation on the standard is permitted.

As there are six States in the Commonwealth, and as each can have a different regulation, attempts have been made to secure uniformity through the intervention of the Commonwealth. The Commonwealth authorities have proposed a standard with a deviation of 30% either way from it.

Such a standard assumes a degree of rigidity in the composition of human milk fit for consumption by infants which is not in accord with the data available. If this standard was applied to the milks of Australian mothers, then 60% of the milks would be condemned as not fit for consumption. Yet the infants thrive on these milks. The difficulty arises from the fact that the standard lays undue stress on the relative concentration of the various constituents, while the nutrition of the infant is determined by the quantity of food consumed. Again, the standard insists on a particular ratio between fat and sugar, while actually these substances can replace one another in the production of the heat of the body.

All those foods composed of milk and digested cereal have too high a concentration in sugar as compared with fat when judged by the canons of the proposed standard. Experience has taught us that these foods are well borne by the infant. The variety in the amino acid is probably an advantage to the

growing infant. It is therefore urged on the health authorities that, until definite information of the harmful character of these preparations is produced, a larger deviation from the standard be permitted, so as to allow those foods in which the heat energy is derived from carbohydrate to be sold without a special label. Such foods contain a high percentage of carbohydrate and a low percentage of fat. In the standard the ratio of carbohydrate to fat is roughly 2: 1, while these foods mostly contain four part of sugar to one of fat. This range is no greater than that found in the milk of many Australian mothers. In these foods most of the starch is converted to sugar, and the standard should determine the maximal amount of starch to be permitted. It is difficult to convert the last traces of starch, so that an absolute prohibition of starch is unnecessarily severe. An amount not exceeding one per cent. of the food would be quite harmless. If the deviation allowed was extended to 50%, then the regulation would be more in accord with the degree of variation present in the food of breast-fed infants.

Shipping Newspapers, Ltd., 16 Bond street, Sydney.

[*From the Proceedings of the Linnean Society of New South Wales, 1912, Vol. xxxvii., Part 1, April 24th.*]

# THE CHEMISTRY OF DORYPHORA SASSAFRAS.

By James M. Petrie, D.Sc., F.I.C., Linnean Macleay Fellow of the Society in Biochemistry.

(*From the Physiological Laboratory of the University of Sydney.*)

*Doryphora sassafras* Endlicher, is the characteristic sassafras tree of New South Wales, as *Atherosperma moschatum* is of Victoria, and *Cinnamomum Oliveri* is of Queensland. Of these, the latter alone belongs to the Lauraceæ, the same Order as the true *Sassafras officinale* of North America; while *Doryphora* and *Atherosperma* are in the N.O. Monimiaceæ.

*D. sassafras* is indigenous to Eastern Australia, and is confined almost entirely to New South Wales. It begins in the south of Queensland, and extends southward almost to the Victorian border, while inland, it is limited by the Blue Mountains and the coastal ranges. It grows to an average height of 50 to 80 feet, but in some places has attained the height of 180 feet.

Aborigines, and also country people, make a tea from the bark, which they drink as a tonic. The light yellow wood possesses the fragrance of the bark, and is not attacked by insects.

About a half hundredweight of bark was collected by Mr. W. H. Waters, near Fitzroy Falls, Moss Vale, in June, 1907, and was identified by Mr. R. T. Baker, Curator of the Technological Museum, from specimens of leaves and fruits. The fragrant odour of the bark in its fresh state was very strong, and during the drying, part of the volatile oil escaped, and the fragrance lessened, and finally became very faint. The air-dried material was laid aside at the time, until a convenient opportunity could be obtained to begin the investigation. During the three years' storage, a considerable portion of the most volatile constituents must have been lost, as the faint aromatic odour persisted throughout, and the air of the storeroom was constantly laden with the vapour.

## Preliminary Analysis.

A small quantity of the powdered bark was first examined to ascertain the general characters of the constituents. It was passed through a 0·5 mm. sieve, and a weighed portion dried at 100°C., to constant weight. The fragrance during the heating was quickly replaced by a disagreeable odour, which persisted to the end. After weighing, the dried material was incinerated and the ash weighed. The following results were obtained :—

| | Air-dried bark. |
|---|---|
| Loss at 100°C.—vol. oil and moisture ... | 11·16% |
| Ash.......... . ...... . ........... ............ .. | 3·48 |
| Organic portion (by difference)............ | 85·36 |
| | 100·00 |

*Action of various Solvents.*—20 gms. of the same powdered sample were next extracted successively with various solvents.

*Petroleum Spirit Extract.*—This was evaporated to dryness at room temperature in a slow air-current, and the residue weighed. This residue possessed the fine fragrance of the volatile oil. When transferred to a desiccator, and the drying continued for a number of days, it continued to lose weight, and on the fourth day the fragrant odour had disappeared. The residue left was a thin pale yellow liquid. It was heated in the oven at 100°C., and attained a constant weight after 16 hours. This residue possessed a disagreeable, slightly pungent odour.

| | | |
|---|---|---|
| Weight of first dry residue..... . . ... | | 1·19% |
| ,, | after 4 days in desiccator ......... | 1·07 |
| ,, | after heating to 100°C.......... .. | 0·40 |
| ,, | of fragrant essential oil . ... . ... | 0·12 |
| ,, | of other volatile oils ................ | 0·67 |

The residue, after heating, consisted of fixed oil, and a little resin. No alkaloids were found in the petroleum spirit extract.

*Ether Extract.*—When evaporated at room temperature, and dried in a desiccator, this amounted to 1·05%. Of this weight, 0·325 was volatilised by heating to 100°, and probably consisted of the same volatile oil as that obtained in the previous extract,

The fixed oil was dissolved out by petroleum spirit, 0·166%. Water removed in solution a part, which gave all the alkaloidal reactions, and there was left 0·234% of insoluble resins.

| | |
|---|---|
| Volatile oil (vol. at 100°C.)................ | 0·325% |
| Fixed oil (sol. in petrol. spirit)...... . .. | 0·166 |
| Resins (insol. in water)..................... | 0·234 |
| Alkaloid, etc. (diff. sol. in water)... ..... | 0·325 |
| | 1·050 |

*Alcohol Extract.*—From the residue, after petroleum spirit, and ether, alcohol extracts 3·2% of solid matter. From this, water removed a substance which gave a very persistent froth. Dilute ammonia dissolved a considerable part, and from this solution, when acidified, a brown deposit separated, mainly consisting of resins soluble in dilute alkali. The water-soluble portion gave a very pale green colour with iron alum, and gelatin solution gave only a small precipitate. The tannins were precipitated by lead acetate, and weighed, after deducting the lead oxide, 1·24%. The filtrate, after removing the lead, was tested with Fehling's solution, but no reducing substances were present either before or after hydrolysis with acid, showing the absence of glucosides. The alcoholic extract contains:—

| | |
|---|---|
| Part insol. in water—resins ... .. .... | 1·00% |
| PbA ppt.—tannins (chiefly) ... ... ........ | 1·24 |
| Other substances ..... . .. .. ............... .. | 0·96 |
| | 3·20 |

*Water Extract.*—This contained 5% of material in solution. From it was separated, mucilage and dextrin in very small amounts. The amount of glucose, or reducing sugars obtained by Fehling's solution, and weighing the CuO, was 1%, and after hydrolysis by boiling with hydrochloric acid for 20 mins., 1·53% of glucose.

| | | | |
|---|---|---|---|
| Total carbohydrate by hydrolysis.... | 1·53% | expressed as | glucose. |
| Reducing sugars ........................ ... | 1·00 | ,, | ,, |
| Saccharose group..................... ..... | 0·53 | ,, | ,, |

The material left after the water extraction was then treated with 1% hydrochloric acid, in order to detect calcium oxalate. The extract was neutralised with ammonia, and precipitated with 2 vols. of alcohol. The flocculent brown deposit was dried and burnt, dissolved in acid, iron and other metals removed, the calcium precipitated as oxalate and titrated. The equivalent of calcium oxalate was 1·23%.

Results of the preliminary examination of air-dried bark :—

| | |
|---|---|
| 1. Extracted by petroleum spirit ........ | 1·19% |
| 2. Extracted by ether ........ | 1·05 |
| 3 Extracted by absol. ethyl alcohol. ........ | 3·20 |
| 4. Extracted by distilled water........ | 5·00 |
| | 10·44 |

The approximate constituents found are :—

| | (a) | | (b) | |
|---|---|---|---|---|
| Volatile essential oils........ | 1·117 | per cent. | 1·24 | per cent. |
| Fixed oils ........ | 0·366 | ,, | 0·63 | ,, |
| Resins........ | 1·234 | ,, | 1·37 | ,, |
| Tannins (etc , pptd. by PbA.) ........ | 1·240 | ,, | 1·38 | ,, |
| Reducing sugars (as glucose). ...... | 1·000 | ,, | 1·11 | ,, |
| Saccharose sugars. ........ | 0·530 | ,, | 0 59 | ,, |
| Calcium oxalate. ........ | 1·230 | ,, | 1·37 | ,, |
| Alkaloid (approx.) ........ | 0·325 | ,, | 0·36 | ,, |

(a) Calculated on air-dry material; (b) on material dried at 100°C.

The prominent features brought to light by the above examination are (1) the existence of a fragrant essential oil, part of which was exceedingly volatile, and passed off into the air at ordinary room temperature. It was found impossible to volatilise the solvent from the ethereal or petroleum spirit solution, in the usual way by a current of air, without losing the greater part of the highly volatile constituents. (2) There was dissolved by alcohol a quantity of aromatic resins; and (3) a small amount of tannin. (4) The presence of an alkaloid was shown.

## Analysis of the Inorganic Portion.

The ash constituted 3·48% of the original bark
3·93% of the bark dried at 100°,

The ash contained 18·33% soluble in water.
70·62% soluble in HCl.
11·05% insol. in HCl.

The entire ash was found to have the following composition, and is compared with the Victorian sassafras, *Atherosperma moschatum*, under the same conditions, from Zeyer's analysis(1).

| | *Doryphora.* | *Atherosperma.* |
|---|---|---|
| Total ash.......... | 3·93 | 4·06 |
| $Na_2O$.......... | 0·263 | 0·396 |
| $K_2O$.......... | 0·102 | 0·164 |
| MgO.......... | 0·069 | 0·177 |
| CaO.......... | 1·450 | 1·845 |
| $Mn_2O_3$.......... | 0·018 | 0·019 |
| $Fe_2O_3$.......... | 0·070 | 0·004 |
| $Al_2O_3$.......... | 0·085 | 0·008 |
| Cl.......... | 0·179 | 0·065 |
| $SO_3$.......... | 0·099 | 0·058 |
| $P_2O_5$.......... | 0·105 | 0·048 |
| Insoluble.......... | 0·434 | 0·056 |
| $CO_2$.......... | -- | 1·220 |

## Bulk Extraction.

For the more complete examination of the constituents of the bark, a large quantity was next treated as in the following scheme:—

Extraction with alcohol.
Steam distillation of the extract, yielding
A. Volatile oil.
B. Aqueous distillate.
C. Insoluble resins.
D. Alkaloid in aqueous solution.

The air-dried bark, weighing 18 kilos., was passed through a powerful disintegrator. and the powder extracted twice with hot 95% methylated spirit. The extract was distilled under diminished pressure, and in the removal of the solvent much of the exceedingly volatile oil was unavoidably lost. The thick tarry liquid left in the still, and measuring about one and a half litres,

was transferred to a large flask, and distilled in a current of steam for many hours. A heavy yellow oil was carried over with the steam, and condensed. The oil was removed by a separating funnel, and the aqueous distillate was shaken up with petroleum spirit, which removed a further amount of oil existing as minute suspended globules. From the latter the solvent was removed, and the yellow oil added to the main portion. The residue in the retort consisted of resins, made insoluble by the loss of the essential oil in which they were originally dissolved, and the alkaloid partly in solution.

## A. The Volatile Oil.

The yield of oil from the steam distillation was 75·3 gms., equivalent to 0·42% of the bark. Since the figure given in the preliminary analysis, 1·117%, was obtained by difference, the following special assay was made to determine more exactly the amount present.

*Special Assay.*—200 gms. of the powdered bark were placed with water in a large distillation flask, and distilled in a current of steam until no more oil collected, using very efficient condensers with ice. The oil was separated, and that remaining suspended in the distillate was recovered by petroleum spirit; the whole weighed 2·06 gms. Equivalent to 1·03% of the bark, or 1·15% of the material dried at 100°.

A second supply of the bark freshly removed from the tree yielded 1·35% of volatile oil (calculated for the dried material).

*Properties of the Essential Oil.*—The oil was pale yellow in colour, and possessed the essential odour of the bark. It was neutral to litmus, phenolphthalein, and m. orange; heavier than water, having a density of 1 033 at 15/15°C. The optical rotation in a 1 dm. tube at 15°, $[\alpha]_D = +7·4°$, and the refractive index at 15°, $[n]_D = 1·5258$.

Hydrochloric acid gas produced a bright purple colour, but no crystals formed showing the probable absence of cineol.

Bromine vapour gave first a red colour, which passed into blue, purple, and green; no crystals were formed.

Concentrated sulphuric acid also produced a succession of bright colours—brown, red, purple, and blue. That this colour reaction is given by the exceedingly volatile constituent of the oil was shown by placing a small quantity in a watch-glass inside a desiccator, over sulphuric acid, when the latter quickly assumed a deep purple tint. The oil lost more than half its volume when kept in a desiccator at room temperature for a few days.

When cooled for some time with ice and salt, a stearoptene separated in the form of white crystals. It redissolved at about 10°C., when the oil was removed from the freezing mixture, and probably consisted of safrol, the methylene ether of allyl dioxybenzene. The quantity was too small for examination.

*Fractional Distillation,*—The volatile oil distilled over between the following limits:—

| *Temperature.* | *Volume.* |
|---|---|
| 60-100°C. | 4% |
| 100-200 | 16 |
| 200-220 | 50 |
| 220-230 | 12 |
| Residue | 18 |

The distillate up to 220° was white in colour, the higher fraction was pale green. All the fractions possessed the odour and pungent taste of clove-oil. At 230° the oil began to decompose and the distillation was stopped. The remaining fluid in the still was black, and solidified on cooling.

*The Essential Oil of the Leaves.*—A sample of fresh leaves, weighing 100 gms., was distilled with steam. The bulky aqueous distillate was shaken out with ether; and after removal of the solvent, the oil was weighed.

| | |
|---|---|
| 100 gms. fresh leaves, dried at 100°, lost .. ..... | 61·60 gms. |
| ,, ,, contained ... | 1·72 gms. oil. |
| | 59·88 gms. moisture. |

The volatile oil amounts to 4·3% calculated on leaves dried at 100°.

*The Essential Oil of the Fruits.*—This was determined in the same way, and yielded 2% on the fresh fruits, or 4% on material dried at 100°. The crushed fruits emitted a strong odour of camphor.

COMPARISON OF ESSENTIAL OILS FROM THE BARK OF FOUR DIFFERENT "SASSAFRAS" TREES.

| | Yield. | Sp gr. | Ref. index. | Rotn. | Safrol. |
|---|---|---|---|---|---|
| *Doryphora* ...... | 1·35 % | 1·033 at 15° | 1·5258 | +7·4° | small amt. |
| *Atherosperma*(2).... | 1·20 | 1·042 at 14° | 1·5274 | +7· | small amt. |
| *Cinnamom. Oliv.*(3). | 0·86 | 1·001 at 16° | ... | +11·038 | small amt. |
| *Sassafras offic.*...... | 6 to 9 | 1·088 | .. | +3·26 | 80-90% |

The numerical properties of the oils of Doryphora and Atherosperma are nearly the same, and it will probably be found that their constituents are the same. They differ entirely from the American sassafras oil of commerce, which has a much greater yield.

Fluckiger,(4) in 1888, stated that in both Doryphora and Atherosperma, the odour was strongly suggestive of safrol. Now in Doryphora oil, the stearoptene which crystallises out on freezing, and melts at about the same temperature as safrol, most probably represents the small amount of this constituent which is present. The recent investigation of the oil of Atherosperma by Miss Scott,(5) of Melbourne, shows that safrol is a constituent. The American oil, when cooled to 0°, becomes solid by the crystallisation of the very large amount of safrol contained in it(6).

Safrol is a constituent of the essential oils in typical members of the following Natural Orders—Monimiaceæ *(Doryphora)*, Lauraceæ *(Sassafras, Cinnamomum, Beilschmiedia)*, Magnoliaceæ *(Illicium)*, Aristolochiaceæ *(Asarum)*; and the chief supply for the world's market is made by the firm of Schimmel and Co., from *Cinnamomum camphora.*

## B. THE AQUEOUS DISTILLATE.

The aqueous distillate, after the oil had been removed by ether, was found to have an acid reaction, and to contain no volatile alkaloid. Part of the solution was exactly neutralised with

baryta, evaporated, and heated to constant weight. The barium salt was then decomposed by sulphuric acid.

0·7065gm. Ba salt gave 0·645gm. $BaSO_4$ = 53·73% Ba; barium acetate requires 53·73% Ba.

The acid is, therefore, acetic acid alone. A part of the distillate was titrated with $\frac{N}{10}$ alkali, and from this, the amount of acetic acid in the whole distillate was found.

Total acetic acid 1·7 gms. = 0·01% of the bark.
= 2·27% of the volatile oil.

This acid is doubtless formed during the steam-distillation, by the partial hydrolysis of acetic esters existing in the original oil.

## C. The Resins.

After the steam-distillation, the residue in the retort was removed while hot, and consisted of aqueous solution and a thick oily semi-solid mass. The latter, containing the resins and fixed oils, was washed repeatedly with hot acidulated water, and in this way the greater part of the alkaloid present was obtained in solution. The solid residue was dissolved in alcohol, and poured into a large volume of water. The sediment which settled was separated and dried.

Its weight was 350 gms., or 1·9% of the bark.

## D. The Alkaloid.

The aqueous solution containing the washings from the resins was concentrated to about 9 litres This solution was treated with lead acetate, and then basic acetate, the precipitates being removed and washed. The filtrate, free from lead and hydrogen sulphide, was now concentrated to 4 litres, and the alkaloid separated by ammonium hydroxide. The voluminous alkaloidal precipitate being filtered off, the solution still contained alkaloid, which was then recovered by shaking with chloroform, and uniting it to the main precipitate.

*Purification.*—The crude alkaloid was now dissolved in dilute sulphuric acid, and precipitated with mercuric potassium iodide. From this, after careful washing, the alkaloid was recovered; it was then precipitated three successive times with ammonia, and

finally extracted with chloroform. This solution on evaporation to dryness left the alkaloid in an amorphous form, and of a yellowish-grey colour.

Attempts were made to obtain the alkaloid in the crystallised condition, but none of these were successful. Saturated solutions of the alkaloid, in water, methyl, ethyl, and amyl alcohols, ether, acetone, chloroform, and benzene, were allowed to evaporate spontaneously; amorphous residues were in all cases obtained. Salts of the alkaloid were next formed by neutralisation with sulphuric, nitric, picric and picrolonic acids; on spontaneous evaporation, not one of these was obtained in a crystallised form.

*Properties of the Alkaloid.*—The amorphous powder is highly electric; when brushing it out from one vessel to another, it either strongly adheres, or flies off and scatters.

The melting point lies between 115° and 117°C. It possesses a slightly bitter taste, and the reaction is faintly alkaline to litmus. It dissolves readily in alcohol, chloroform, and dilute acids; is very slightly soluble in ether, and water; and insoluble in petroleum spirit. The solutions are yellow to brown.

Concentrated sulphuric acid placed on a speck of the alkaloid on a white slab produces a pinkish-brown colour. No other colour reactions were observed. The alkaloid is precipitated from its salt solutions by ammonium hydroxide, sodium hydroxide, carbonate, and bicarbonate, picric acid and picrolonic acid, iodine, potassium mercuric iodide, tannic, phosphotungstic, and phosphomolybdic acids.

*Titration of the Alkaloid.*—Of the amorphous powder, 0·9614 gm. dissolved in hot water, required 28 cc. of $\frac{N}{10}$ sulphuric acid, $=$ 0·1372 gm., to neutralise it to litmus.

0·1372 acid : 0·9614 alkaloid :: 49 : 343.

The equivalent weight of alkaloid is thus shown to be 343.

*Assay of Bark for Alkaloid.*—(a) 10 gms. of powdered bark were extracted in a soxhlet with alcohol. From the extract the solvent was distilled, the residue dissolved in dilute hydrochloric acid, water added, and filtered. From the filtrate the alkaloid

was precipitated by 9 cc. of Mayer's reagent.* This precipitate was decomposed with sodium sulphide, and the alkaloid obtained as hydrochloride. The solution was made alkaline with ammonia, and shaken out three times with chloroform. The chloroformic solution was evaporated in a weighed dish. The weight of alkaloid obtained was 0·0536 gm.

(b) 100 gms. of bark were extracted with hot alcohol as before. After removing the spirit, the residue was treated with water, and the resins filtered off. The small amount of tannin was separated by lead acetate, and the alkaloid obtained by precipitation with ammonia. The alkaloid which still remained in solution, was removed by agitating with chloroform, and added to the precipitate. The latter was then dissolved in alcohol, excess of standard acid added, and then titrated back to the neutral point with alkali, using sensitive litmus as indicated. Required 16·3 cc. $\frac{N}{10}$ acid.

(c) 10 gms. were treated as before, and the alkaloid obtained by agitating the aqueous solution with chloroform. The latter was evaporated, and the residue, which weighed 0·149 gm., was titrated. Required 1·55 cc. $\frac{N}{10}$ acid,

Results :—(b) 16·3 cc. $\frac{N}{10}$ sulphuric acid.
(c) 15·5 ,,

mean 15·9 cc. = 0·0786 gm. sulphuric acid.
49 acid : 343 alkaloid : : 0·0786 : 0·55
therefore amount of alkaloid in bark... = 0·55 by titration.
0·536 by weighing.

calculated on air-dried bark, mean......... 0·54%

and calculated on material dried at 100°C. 0·63%

*Alkaloid in the Leaves and Fruit.*—Samples of the bark, leaves and fruit were examined simultaneously by method (a). After distilling off the alcohol, and extracting with acidulated water, they were each titrated under the same conditions, with Mayer's reagent. The volumes required were

* Potassium mercuric iodide.

respectively—bark 100 cc., leaves 55 cc., fruit 20 cc.; so that the approximate amount of alkaloid in the leaves is 0·3%, and in the fruit 0·1% (calculated on the dried material).

*Ultimate Analysis of the Alkaloid.*—The following data were obtained by analysis of the amorphous powder, and must, therefore, be considered as provisional only.

Combustions.—

0·1808 gm. gave $\begin{cases} 0·455 \text{ gm. } CO_2, C = 68·64 \text{ per cent.} \\ 0·102 \text{ gm. } H_2O, H = 6·27 \quad ,, \end{cases}$

0·1541 gm. gave $\begin{cases} 0·3904 \text{ gm. } CO_2, C = 69·09 \quad ,, \\ 0·0886 \text{ gm. } H_2O, H = 6·39 \quad ,, \end{cases}$

Nitrogen by Dumas' method.—

0·219 gm. gave 8·2 cc. N gas at 23·1°C. and 758 bar. N = 4·20%.

0·193 gm. gave 7·2 cc. N gas at 21·2°C. and 766 bar. N = 4·27%.

Nitrogen by Kjeldahl's method using zinc dust, salicylic acid, potassium H sulphate, and sulphuric acid—

0 407 gm. required 12 6 cc $\frac{N}{10}$ acid. N = 4 33%

Results—

| | Found | | | Required for | | |
|---|---|---|---|---|---|---|
| | (i) | (ii) | | $C_{18}H_{21}NO_4$ | $C_{19}H_{21}NO_4$ | $C_{20}H_{21}NO_4$ |
| C | 68·64 | 69·09 | | 68·60 | 69·70 | 70·80 |
| H | 6·27 | 6·39 | | 6·66 | 6·42 | 6·20 |
| N | 4·33 | 4·27 | 4·20 | 4·44 | 4·28 | 4·13 |
| O | 20·76 | 20·25 | | 20·30 | 19·60 | 18 90 |

$C_{18}$ is hydroxycodeine, mol. wt. ......... 315.
$C_{19}$ is tubocurarine, mol wt .. ....... 327.
$C_{20}$ is papaverine and canadine. . .. ... 339.

*Physiological Action of the Alkaloid.*—A definite weight of the amorphous alkaloid was converted into sulphate, and dissolved in normal saline. This solution was injected into the lymph sacs of frogs (*Hyla aurea* and *Limnodynastes*), and 1 mg. doses proved fatal. In 1 to 5 mins. after injection, the frogs became sluggish, their activity quickly decreased, so that they were soon unable to turn over, when laid on their backs. The voluntary muscles, first of the hind limbs, then of the fore limbs, were relaxed, and the reflexes disappeared entirely. In this general comatose condition, respiration

gradually became slower and weaker, till it ceased. In no cases were spasmodic reflexes or convulsions observed.

The effect on the heart was observed by exposing the heart of a pithed frog, and applying a 1 % solution of the alkaloid in normal saline. The beat became slower, and within 8-10 minutes stopped, with the ventricle in the systolic phase.

Muscle and nerve preparations were made from both Hylas and Limnodynastes. The muscle of one preparation and the nerve of another were laid in a watch-glass containing the solution of alkaloid, and the excitability tested. No alteration in the response was observed when nerve or muscle was stimulated by a faradic current.

### Comparison with other allied Plants.

Of the twenty-two known genera of the Monimiaceæ, eight are represented in Australia; and of the latter, four—*Doryphora, Daphnandra, Palmeria,* and *Piptocalyx*, are found only in Australia.

About the year 1860, von Mueller sent a quantity of the Victorian sassafras, *Atherosperma moschatum*, to Professor Wittstein in Germany. It was handed over to the chemist Zeyer, who investigated its composition, and published his work in the Jahresbericht for 1861(7). The following comparison is made from an abstract in Wittstein's "Analyse von Pflanzen":—

The alkaloids of *Doryphora* and *Atherosperma* resemble one another in being precipitated by ammonia as bulky flocculent precipitates. When dry they are light, loose, highly electric powders, without odour, but possessing a bitter taste. Though almost white or pale gray in colour when first precipitated, they gradually become brown on exposure to light and air. They are nearly insoluble in water, and very faintly in ether, highly soluble in alcohol, chloroform, and dilute acids. They are neutralised by acids giving varnish-like salts.

The two alkaloids differ in their melting points, *Atherospermine* m.p. 128°, while the *Doryphora* alkaloid m.p. is 115-117°,

Zeyer gave his alkaloid the formula $C_{30}H_{40}N_2O_8$ (old German $C_{30}H_{20}NO_6$), though he regarded it as doubtful at the time.

The provisional formula arrived at for the *Doryphora* alkaloid is $C_{18}H_{21}NO_4$.

In New Zealand there occurs another genus of the Monimiaceæ, *Laurelia Novæ-Zealandeæ*, whose bark and leaves were found by Bancroft(8) to possess "an agreeable aromatic bitter taste." From this bark, Aston(9) isolated three alkaloids, one (laureline) having the formula $C_{19}H_{21}NO_3$, and m.p. 116°, was amorphous, but formed crystallised salts; another, was also an amorphous powder, from which no crystallised salts could be obtained. The physiological action of the chief alkaloid, as described by Professor Malcolm(10), shows first, a stage of increased excitability, quickly followed by complete loss of power and death. The second stage closely resembles that produced by the alkaloid of *Doryphora*

*Piptocalyx Moorei*(11), the "Bitter Vine" of New South Wales, owes its intensely bitter taste to a glucoside, which was examined by Umney(12) in London, and no alkaloids were detected.

The only other members of this Order, native to Australia, and whose constituents have been examined, are the three species of *Daphnandra*,—*repandula*, *micrantha*, and *aromatica*. Bancroft(13) has recorded the presence of bitter alkaloids in all parts of these plants, and found them to be powerful poisons. The physiological action on frogs resembled that of the *Laurelia*, producing convulsive movements, followed by paralysis.

Of the extra-Australian genera, *Monimia rotundifolia* was examined by Rochebrune(14) in 1897. He found in it a glucoside, a volatile oil and an alkaloid having properties almost identical with those of the constituents of the Chilian genus, *Peumus boldus*(15). The alkaloid of *Peumus* resembles that of *Doryphora* in many of its properties, both chemical and physiological, and it, too, could not be obtained in a crystallised form,

Therefore, it will be seen by these comparisons, that the alkaloid of *Doryphora* differs from that of the closely related genera in the absence of a first, or tetanic stage. But in all cases they are alike in their later stages. Many plants of the N.O. Lauraceæ, on the other hand, were shown by Greshoff (16) to contain laurotetanine, an alkaloid of the convulsive group.

### Relation to other Alkaloids.

(i) A consideration of the properties of the alkaloid from *Doryphora* brings out the following features. (*a*) The similarity of its properties to those of its nearest botanical ally—the atherospermine of Zeyer. (*b*) The molecular formula comes nearest to hydroxycodeine, $C_{18}H_{21}NO_4$. This was obtained by Knorr, through the oxidation of codeine, and discovered by Dobbie and Lauder(17), last year, in the mother-liquor of the opium alkaloids, after all the other members had been eliminated. (*c*) The formula lies also very close to $C_{19}H_{21}NO_4$, given by Boehm(18) to tubocurare, which is a brown amorphous base, bitter and poisonous. (*d*) It also approaches that of Aston's laureline ($C_{19}H_{21}NO_3$), as well as (*e*) members of the hydrastine group of alkaloids. Of the latter group, canadine($C_{20}H_{21}NO_4$), is a hydroberberine, an alkaloid found in the Berberidaceæ, Ranunculaceæ, and Menispermaceæ. It resembles berberine in the yellow colour of its powder, and solutions, as also that of its salts. (*f*) In the morphine group, the formula approaches papaverine($C_{20}H_{21}NO_4$).

(ii) On the other hand, the properties of the alkaloid diverge from the characteristic properties of the above compounds, in the following way:—(*a*) The molecular formula, and melting point are far removed from Zeyer's figures for atherospermine. (*b*) It does not yield the characteristic colour reactions of codeine, and hydroxycodeine melts at about 51° C. (*c*) It does not show the typical curare action on the receptive substance of the motor nerve endings in muscle, when administered to frogs. (*d*) Unlike laureline, it does not produce convulsions. (*e*) The physiological action excludes the hydrastine

group of alkaloids, for the same reason as in curare. (*f*) The physical properties are different from those of papaverine.

## SUMMARY.

*Doryphora sassafras* is a small Monimiaceous tree, endemic in Eastern Australia. Its bark, leaves, and fruit contain an essential oil of characteristic sassafras odour. The oil has a density of 1·033, and distils between 60° and 230°C. The bark contains 1·35%, leaves 4·3%, and fruit 4% (% on material dried at 100°). The essential oil is compared with that from the Victorian sassafras, *Atherosperma moschatum*, the Queensland sassafras, *Cinnamomum Oliveri*, and the *Sassafras officinale* of N. America.

*Other constituents* of the bark are fixed oil 0·63%, aromatic resins 1·3%, tannins 1·3%, sugars 1·7%, calcium oxalate 1·37%, and an alkaloid 0·63% (% on bark dried at 100°).

*The alkaloid* is an amorphous grey powder. All attempts to obtain it, or its salts, in a crystalline form, were unsuccessful. The alkaloid is highly electric, m.p. 115-117°C., with a bitter taste and alkaline reaction; readily soluble in alcohol, chloroform, and dil. acids, very slightly in ether and water, insoluble in petroleum spirit. The solutions are yellow. Composition: C—68·64%, H—6·27%, N—4·33%, O—20·76%, corresponding closely to $C_{18}H_{21}NO_4$. The amount of alkaloid in the bark is 0·63%, in the leaves 0·3%, and in the fruit 0·1% (% on material dried at 100°).

*The physiological action* on the frog shows loss of power of movement, and of response to touch, paralysis and death. The min. lethal dose for *Hyla aurea*, a 13 gm. frog, is 1 mgm. No convulsions are produced, and the alkaloid has no action on nerve, receptive substance, or muscle.

*The biochemical relationships* of Doryphora are compared with other members of the same natural order. The alkaloid is compared with the active principles of allied plants, and also with alkaloids of approximately the same composition. After discussing the points of resemblance and difference in their properties, it is concluded that the alkaloid is a new one, and the name proposed for it is "DORYPHORINE."

Bentham and Hooker separate the Monimiaceæ and Lauraceæ with the monochlamydeous plants, but in Engler's classification we find the natural orders grouped closely together, which contain all the alkaloids mentioned above, except curare. From this comparison it is shown that the bark of *Doryphora sassafras* contains a new alkaloid, hitherto unrecorded, for which the name "Doryphorine" is proposed.

I wish, in conclusion, to express my indebtedness to Professor Anderson Stuart and Dr. Chapman, for affording every convenience to the carrying out of this investigation.

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POSTSCRIPT: *added July 3rd, 1912.*—The following observations, referring to the action of alkaloids on Australian frogs, were offered by Mr. E. C. Grey, B.Sc., Junior Demonstrator in Physiology, after the paper was read—With reference to Dr. Petrie's communication on the Chemistry of Doryphora, it was of importance to bear in mind that the behaviour of Australian frogs towards alkaloids had not yet been properly ascertained. Moreover the same alkaloid sometimes affected different frogs in different ways. He had observed the effect of Brucine on some Australian frogs, and had found that the strongly muscular Limnodynastes showed convulsions, whereas none were produced in any of the Hylas examined.

[*From the Proceedings of the Linnean Society of New South Wales, 1912, Vol. xxxvii., Part 1, April 24th.*]

# HYDROCYANIC ACID IN PLANTS.

## PART i.—ITS DISTRIBUTION IN THE AUSTRALIAN FLORA.

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It is now more than a century since Boehm, the Berlin apothecary, obtained hydrocyanic acid by distilling the water in which bitter almonds had been steeped. This was the first discovery of the formation of hydrocyanic acid by plants. Since that time this acid had been detected in a number of well-characterised plants, such as the cherry-laurel, rubber-tree, and cassava, but up to the end of last century the list of such plants was very small. At this period, theoretical speculations on the rôle of hydrocyanic acid in metabolism created a new and wider interest in the subject, and resulted in the initiation of two separate lines of research:—(1) The biochemical problems connected with the origin and fate of hydrocyanic acid in plants, and (2) the detection of this substance, in order to determine its occurrence and distribution throughout the vegetable kingdom.

The first systematic examination for hydrocyanic acid in plants was begun by Greshoff, in the Botanic Gardens of Buitenzorg, and later, at Kew. He published, in 1906, a complete list of all the known cyanogenetic plants, and a further supplement, prior to his death, in 1909.

In this list are included only four plants native to Australia. The present investigation may therefore be considered as a continuation of similar work on the indigenous flora of Australia. The majority of the plants have been collected by me personally, in the bush. A number were obtained from

plants growing in the Botanic Gardens, through the kindness of the Director, Mr. J. H. Maiden, to whom my thanks are due.

## Methods Used.

i. Parts of plants were cut up and steeped in water at 40° C. for 24 hours.

(*a*) Alone.

(*b*) With addition of emulsin prepared from sweet almonds, or an aqueous extract of the emulsin.

(*c*) With addition of 1 cc. of a 0.5 per cent. solution of amygdalin, prepared by extraction from bitter almonds, and recrystallisation.

ii. Parts of plants were plasmolysed by the vapour of chloroform. Guignard, and Mirande have shown that the vapour penetrates the living cells, and incites the retraction of the protoplasm, with the result that the cells are finally killed. There then takes place, an increased outward diffusion from the interior of the tissues, of water containing the different substances previously localised in the living plant: that is, a diffusion of the glucoside and enzyme from their respective cells. These substances are then free to react chemically, and since the products are volatile, they can be recognised in the vapour.

iii. The method of identification of the vapour of hydrocyanic acid is the colour change of sodium picrate paper from yellow to red. This test was first used by Professor Guignard, who ascribed the change to a reduction of the picrate to isopurpurate by the hydrocyanic acid.

In the following table the plants are arranged in the order of the botanical classification in the Flora Australiensis, and the results are entered in three columns as positive and negative.

Col. i.—Plant tested alone with water, or chloroform: + here indicates the existence of both a cyanogenetic glucoside, and an emulsin-like ferment.

Col. ii.—Plant with emulsin added: + here *alone*, indicates presence of glucoside and no ferment in the plant.

Col. iii.—Plant with amygdalin added: + here *alone*, shows the existence in the plant of a ferment capable of cleaving amygdalin.

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| **RANUNCULACEÆ.** | | | |
| *Clematis aristata* .. | | | |
| *glycinoides* . | | | |
| *microphylla* | | | |
| **DILLENIACEÆ.** | | | |
| *Hibbertia diffusa* (Bot. Gards.) | | | |
| *volubilis* ... ... ... ... ... | | | |
| **MAGNOLIACEÆ.** | | | |
| *Drimys dipetala* ... ... ... ... ... ... ... ... ... ... ... | + | | |
| *aromatica* (Greshoff, 1909) ... ... ... ... | + | | |
| **BIXINEÆ.** | | | |
| *Scolopia Brownii* (Bot. Gards.) ... ... ... ... ... | – | | |
| **PITTOSPOREÆ.** | | | |
| *Pittosporum revolutum* ... ... ... ... ... ... ... .. | – | | |
| *undulatum* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *phillyrœoides* ... ... ... ... ... ... ... .. ... | – | | |
| *Hymenosporum flavum* (Bot. Gards.) ... ... ... | – | | |
| *Bursaria spinosa* ... ... ... ... ... ... .. ... ... | – | | |
| *Citriobatus multiflorus* ... ... ... ... ... ... ... | – | | |
| *Sollya heterophylla* (Bot. Gards.) ... ... ... ... | – | | |
| **POLYGALEÆ.** | | | |
| *Polygala Sibirica* ... ... ... ... ... ... ... ... ... . . | – | | |
| *Comosperma volubile* ... ... ... ... ... ... ... ... ... | – | | |
| *ericinum* ... ... ... ... ... ... ... ... ... ... | – | | |

| | I. Alone | II. Em. | III. Am. |
|---|---|---|---|
| **Malvaceæ.** | | | |
| *Howittia trilocularis* .. ... ... .. ... | | | |
| **Sterculiaceæ.** | | | |
| *Sterculia quadrifida* (Bot. Gards.) | | | |
| *diversifolia* ... ... ... ... ... ... | | | |
| *rupestris* ... ... ... .. .. ... | | | |
| *Tarrietia argyrodendron* ... .. ... | | | |
| *Lasiopetalum ferrugineum* ... ... ... | | | |
| **Tilliaceæ.** | | | |
| *Echinocarpus australis* (Bot. Gards.) ... ... ... | – | | |
| *Elæocarpus cyaneus* ... .. . . ... ... ... ... ... ... ... | – | | |
| **Linaceæ.** | | | |
| *Linum marginale* ... .. ... ... ... ... ... . ... ... ... | + | | |
| **Geraniaceæ.** | | | |
| *Oxalis corniculata* ... ... .. .. ... ... . ... ... ... | – | | |
| **Rutaceæ.** | | | |
| *Zieria lævigata* ... . . ... ... ... ... ... ... .. ... ... | + | | |
| *pilosa* .. .. ... ... ... ... ... ... ... ... ... . | – | | |
| *Smithii* ... .. ... ... ... ... ... ... ... ... ... ... | + | | |
| *Boronia ledifolia* ... ... .. . .. ... ... ... ... . ... | – | | |
| *pinnata* .. ... .. ... ... ... ... ... ... ... ... .. | – | | |
| *Barkeriana* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Crowea saligna* ... . . . .. .. ... ... ... ... ... ... | – | | |
| *Eriostemon buxifolius* ... ... ... ... ... ... ... ... | – | | |
| *lanceolatus* ... ... .. ... ... ... . ... ... | – | | |
| *Phebalium dentatum* ... ... ... . ... ... ... ... .. | – | | |
| *squamulosum* (Bot. Gards.) ... ... ... ... | – | | |
| *Evodia micrococca* .. ... ... . . ... ... ... ... ... | – | | |
| *Geijera parviflora* (Bot. Gards.) ... ... ... ... ... | – | | |
| *Halfordia drupifera* (Bot. Gards.)... ... ... ... ... | – | | |
| *Citrus australis* (Bot. Gards.) ... .. ... ... ... | – | | |

| | i. Alone | ii. Em. | Am. |
|---|---|---|---|
| **OLACINEÆ.** | | | |
| *Olax stricta* ... ... ... ... ... ... . | | | |
| **RHAMNACEÆ.** | | | |
| *Pomaderris lanigera* ... ... ... | | | |
| *elliptica* ... ... ... ... ... ... | | | |
| *phillyreoides* ... ... ... | | | |
| *cinerea* ... ... ... ... ... ... | | | |
| *Cryptandra amara* ... ... ... . | | | |
| **VINIFERÆ.** | | | |
| *Vitis hypoglauca* ... ... ... ... | | | |
| **SAPINDACEÆ.** | | | |
| *Diploglottis Cunninghamii* ... ... ... | | | |
| *Cupania semiglauca* (Bot. Gards.) | | | |
| *anacardioides* ... ... ... ... | | | |
| *tomentella* ... ... ... ... ... ... | | | |
| *Nephelium leiocarpum* ... ... ... ... | | | |
| *Dodonæa triquetra* ... ... ... ... ... | | | |
| *viscosa* (Bot. Gards.) ... ... | | | |
| **LEGUMINOSÆ.** | | | |
| *Oxylobium trilobatum* ... ... .. | | | |
| *Mirbelia grandiflora* ... ... ... . | | | |
| *Gompholobium latifolium* ... .. | | | |
| *minus* ... ... ... ... ... ... .. | | | |
| *Jacksonia* sp. ... ... ... ... ... .. | | | |
| *Daviesia corymbosa* ... ... ... .. | | | |
| *brevifolia* (Bot. Gards.). | | | |
| *Phyllota phylicoides* ... ... ... . | | | |
| *Pultenæa daphnoides* ... ... ... | | | |
| *stipularis* ... ... ... ... .. | | | |
| *polifolia* ... ... ... ... .. | | | |
| *elliptica* ... ... ... ... ... . | | | |

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| *Pultenæa Deanei* ... ... ... ... ... ... ... ... ... . . . | – | | |
| *Dillwynia floribunda* ... ... ... ... ... ... ... ... ... | – | | |
| *Platylobium formosum* ... ... ... ... ... ... . . | – | – | |
| *Bossiæa heterophylla* ... ... ... ... ... ... ... ... ... | – | | |
| *scolopendria* ... ... ... ... . . ... ... ... ... | – | | |
| *Lotus corniculatus* (Bot. Gards.) ... . . ... ... ... | + | | |
| *australis* (Dunstan and Henry, 1900) | + | | |
| *Indigofera australis* ... ... ... ... ... ... ... ... .. | – | | |
| *Swainsona coronillifolia* (Bot. Gards.) ... ... .. | – | | |
| *Cadelli* (Bot. Gards.) ... ... ... ... ... ... ... | – | | |
| *Acacia juniperina* ... ... ... ... ... ... ... ... ... | – | – | |
| *oxycedrus* ... ... ... ... ... ... ... ... ... ... . . | – | | |
| *suaveolens* ... ... ... ... ... ... ... ... ... . | – | – | – |
| *linifolia* ... ... ... ... ... ... ... ... ... ... . | – | | |
| *longifolia* . . ... ... ... ... ... ... ... ... . . | – | | |
| *floribunda* .. ... ... ... ... ... ... ... .. . . | – | | |
| *elata* ... ... ... ... ... ... ... ... ... ... ... . . | – | | |
| *discolor* ... ... ... ... ... ... ... ... . . . | – | – | – |
| *decurrens* ... ... ... ... ... ... ... .. ... . . | – | | |

ROSACEÆ.

*Rubus parvifolius* ...
*moluccanus* ...
*rosæfolius* ...
*Agrimonia eupatoria*
*sanguisorbæ* ...

SAXIFRAGEÆ.

| | i. | ii. | iii. |
|---|---|---|---|
| *Quintinia Sieberi* ... ... ... ... ... ... ... ... ... | – | | |
| *Callicoma serratifolia* ... ... ... . . . ... ... ... | – | | |
| *Ceratopetalum gummiferum* ... ... ... ... ... ... | – | | |
| *apetalum* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Davidsonia pruriens* (Bot. Gards.) ... ... ... ... | + | | |
| *Bauera rubioides* ... ... ... ... ... ... ... ... ... | – | | |

| | i. Alone | ii. Em | iii. Am. |
|---|---|---|---|
| **CRASSULACEÆ.** | | | |
| *Tillæa verticillaris* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| **DROSERACEÆ.** | | | |
| *Drosera spathulata* ... ... ... ... ... ... ... ... ... ... | + | + | + |
| *peltata* ... ... ... ... ... ... ... ... ... ... ... ... ... | + | + | + |
| *binata* (Greshoff, 1909) ... ... ... ... ... ... | + | | |
| **HALORAGEÆ.** | | | |
| *Haloragis salsoloides* ... ... ... ... ... ... ... ... ... | – | | |
| **MYRTACEÆ.** | | | |
| *Darwinia fascicularis* ... ... ... ... ... ... ... ... ... | – | | |
| *taxifolia* ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Bæckea diffusa*... ... ... . . ... ... ... ... ... ... ... | – | | |
| *crenulata* ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *linifolia* ... ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Leptospermum flavescens* ... ... ... ... ... ... ... | – | | |
| *scoparium* ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *arachnoideum* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Kunzea capitata* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Callistemon lanceolatus* ... ... ... ... ... ... ... ... | – | | |
| *linearis* ... ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Melaleuca thymifolia* ... ... ... ... ... ... ... ... ... | – | | |
| *linariifolia* ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Angophora cordifolia* ... ... ... ... ... ... ... ... ... | – | | |
| *lanceolata* ... ... ... ... ... . . ... ... ... ... ... | – | – | – |
| *Eucalyptus* spp. ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Tristania neriifolia* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Rhodomyrtus psidiodes* (Bot. Gards.) ... ... ... | – | | |
| *Eugenia Smithii* ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Luehmanni* (Bot. Gards.) ... ... ... ... ... ... | – | | |
| **PASSIFLOREÆ.** | | | |
| *Passiflora Herbertiana* ... ... ... ... ... ... ... ... ... | + | + | + |
| *cinnabarina* ... ... ... ... ... ... ... ... ... ... ... | + | + | + |
| *brachystephanea* ... ... ... ... ... ... ... ... . | + | + | + |

| | i. Alone | ii. Em. | iii Am |
|---|---|---|---|
| **UMBELLIFERÆ.** | | | |
| *Siebera linearifolia* | | | |
| *Billardieri* ... | | | |
| *Actinotus helianthi* | | | |
| *minor* ... ... | | | |
| **ARALIACEÆ.** | | | |
| *Astrotrica longifolia.* | | | |
| *Panax Murrayi* ... | | | |
| **LORANTHACEÆ.** | | | |
| *Loranthus celastroides* ... ... ... ... ... ... ... .. .. | – | | |
| **CAPRIFOLIACEÆ.** | | | |
| *Sambucus xanthocarpa* (Bot. Gards.) ... ... .. | – | | |
| *Gaudichaudiana* (Bot. Gards.) ... ... ... | – | | |
| **RUBIACEÆ.** | | | |
| *Pomax umbellata* ... ... ... ... ... ... ... ... ... ... | + | | |
| **COMPOSITÆ.** | | | |
| *Olearia ramulosa* ... ... ... ... ... .. . . ... . . . . | – | | |
| *Bidens tripartitus* ... ... ... ... ... ... ... ... ... .. | – | | |
| *Cassinia aculeata* ... ... ... ... ... ... ... ... .. . | – | | |
| *Humea elegans* ... ... ... ... ... ... ... ... .. ... | – | | |
| *Helichrysum elatum* ... ... ... ... ... ... ... .. | – | | |
| *diosmifolium* ... ... ... ... ... ... ... . . | – | | |
| *Senecio Australis* ... ... .. ... ... ... ... ... ... ... | – | | |
| **STYLIDEÆ.** | | | |
| *Stylidium graminifolium* ... ... ... ... .. ... ... | – | | |
| **GOODENIACEÆ.** | | | |
| *Goodenia heterophylla* ... . . ... ... ... ... ... ... | – | | |
| *Scævola hispida* ... ... ... ... ... ... ... ... ... ... | – | | |
| *suaveolens* . . ... ... ... ... ... ... ... ... | – | | |
| *Dampiera Brownii* ... ... .. ... ... ... ... ... ... | + | | |

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| **CAMPANULACEÆ.** | | | |
| *Lobelia gracilis* | | | |
| **EPACRIDEÆ.** | | | |
| *Styphelia longifolia* | | | |
| *triflora* | | | |
| *tubiflora* | | | |
| *Trochocarpa pumila* | | | |
| *Lissanthe strigosa* | | | |
| *Leucopogon amplexicaulis* | | | |
| *lanceolatus* | | | |
| *microphyllus* | | | |
| *virgatus* | | | |
| *ericoides* | | | |
| *esquamatus* | | | |
| *Epacris longiflora* | | | |
| *obtusifolia* | | | |
| *pulchella* | | | |
| *purpurascens* | | | |
| *Woollsia pungens* | | | |
| *Sprengelia incarnata* | | | |
| *Dracophyllum secundum* | | | |
| **JASMINEÆ.** | | | |
| *Notelaea longifolia* | | | |
| **APOCYNEÆ.** | | | |
| *Alstonia constricta* (Bot. Gards.) | | | |
| **ASCLEPIADACEÆ.** | | | |
| *Sarcostemma australe* | | | |
| *Marsdenia suavolens* | | | |
| *Hoya carnosa* (Bot. Gards.) | | | |
| **LOGANIACEÆ.** | | | |
| *Mitrasacme polymorpha* | | | |
| *Logania floribunda* | | | |

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| **SOLANACEÆ.** | | | |
| *Solanum nigrum* ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *vescum* ... ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *stelligerum* ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *armatum* ... ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *campanulatum*... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Nicotiana suaveolens* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Duboisia myoporoides* ... ... ... ... ... ... ... ... ... | – | | |
| **BIGNONIACEÆ.** | | | |
| *Tecoma australis* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| **MYOPORINEÆ.** | | | |
| *Myoporum acuminatum* (Bot. Gards.) .. .. . | – | – | + |
| *Eremophila maculata* (Brünnich & Smith, 1910) | + | + | + |
| **VERBENACEÆ.** | | | |
| *Chloanthes stœchadis* ... ... ... ... ... ... ... ... ... | – | | |
| **LABIATÆ.** | | | |
| *Mentha australis* (Bot. Gards.) ... ... ... ... ... ... | – | | |
| *Prostanthera Sieberi* ... ... ... ... ... ... ... ... ... ... | – | | |
| **CHENOPODIACEÆ.** | | | |
| *Kochia pyramidata* ... ... ... ... | | | |
| **NYCTAGINEÆ.** | | | |
| *Boerhaavia diffusa* ... ... ... ... | | | |
| **MONIMIACEÆ.** | | | |
| *Doryphora sassafras* ... ... | | | |
| *Atherosperma moschatum* | | | |
| **LAURACEÆ.** | | | |
| *Cryptocarya triplinervis* | | | |
| *Litsea dealbata*... ... ... . | | | |
| *Cassytha glabella* ... ... . | | | |
| *paniculata* ... ... . | | | |

## PROTEACEÆ.

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| *Petrophila pulchella* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Isopogon anethifolius* ... ... ... ... ... ... ... ... ... | – | | |
| *ceratophyllus* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Conospermum angustifolium* ... ... ... ... ... ... ... | – | | |
| *Symphyonema montanum* ... ... ... ... ... ... ... ... | – | | |
| *Buckinghamia celsissima* (Bot. Gards.) ... . ... | – | | |
| *Persoonia ferruginea* ... ... ... ... ... ... ... ... ... | – | | |
| *salicina* ... ... ... ... ... ... ... ... ... ... ... .. | – | | |
| *pinifolia* ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Macadamia integrifolia* (Bot. Gards.) ... . | + | + | + |
| *ternifolia* (Greshoff, 1909) (Bot. Gards.) | + | + | + |
| *Xylomelum pyriforme* ... ... ... ... ... ... ... . | + | | |
| *Lambertia formosa* ... ... ... ... ... ... ... ... ... | + | | |
| *Grevillea acanthifolia* ... ... ... ... ... ... ... . | – | | |
| *buxifolia* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *sphacelata* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *punicea* | | | |
| *oleoides* | | | |
| *sericea* ... ... ... ... ... ... ... ... ... ... ... .. | – | | |
| *linearis* ... ... ... ... ... ... ... ... ... ... ... | – | – | |
| *Hakea pugioniformis* ... ... ... ... ... ... ... ... | – | | |
| *saligna* ... ... ... ... .. ... ... ... ... ... | – | | |
| *gibbosa* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *acicularis* ... ... ... ... ... ... ... ... ... ... | – | | |
| *dactyloides* ... ... ... ... ... ... ... ... ... ... | – | | |
| *elliptica* (Bot. Gards.) ... ... ... ... ... ... | – | | |
| *trifurcata* (Bot. Gards.) ... ... ... ... ... | | | |
| *Telopea speciosissima* ... ... ... ... ... ... ... ... | + | | |
| *Lomatia longifolia* ... ... ... .. ... ... ... ... | + | + | + |
| *silaifolia* ... ... ... ... ... ... ... ... ... ... | – | – | |
| *Stenocarpus sinuatus* ... ... ... ... ... ... ... .. | – | | |
| *salignus* ... ... ... ... ... ... ... ... ... ... ... | – | | |
| *Banksia ericifolia* .. ... ... ... ... ... ... . .. | – | – | – |
| *spinulosa* ... ... ... ... ... ... ... ... ... . | – | – | – |

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| *Banksia marginata* ... ... ... ... ... ... ... .. | — | | |
| *integrifolia* ... ... ... ... ... ... ... ... ... ... ... | — | | |
| *latifolia* ... ... ... ... ... ... ... ... .. . | — | | |
| *serrata* ... ... ... ... ... ... ... ... ... ... ... ... | — | — | |
| **EUPHORBIACEÆ.** | | | |
| *Amperea spartioides* ... ... ... ... ... ... ... ... ... ... ... | — | | |
| *Phyllanthus* sp. ... ... ... ... ... ... . . ... ... ... | — | — | — |
| *Breynia oblongifolia* ... ... ... ... ... ... ... ... ... | — | | |
| *Croton phebalioides* (Bot. Gards.) ... ... .. .. | — | | |
| *Carumbium populifolium* ... ... ... ... ... ... ... | — | — | — |
| **URTICACEÆ.** | | | |
| *Ficus rubiginosa* ... ... ... ... . | | | |
| *macrophylla* ... ... ... . | | | |
| *Laportea moroides* ... ... ... .. | | | |
| **CASUARINEÆ.** | | | |
| *Casuarina suberosa* ... ... ... . | | | |
| **SANTALACEÆ.** | | | |
| *Choretrum lateriflorum* . . . . | | | |
| *Leptomeria acida* ... ... ... ... | | | |
| *Omphacomeria acerba*... ... ... | | | |
| *Exocarpus cupressiformis* ... . | | | |
| **CONIFERÆ.** | | | |
| *Callitris* sp. ... ... ... ... ... ... | | | |
| **CYCADEÆ.** | | | |
| *Macrozamia spiralis* ... ... ... | | | |
| *flexuosa* | | | |
| **ORCHIDEÆ.** | | | |
| *Dendrobium speciosum* ... ... | | | |
| *Cymbidium suave* ... ... ... ... | | | |
| *Glossodia major* ... ... ... ... | | | |
| *minor* ... ... ... ... ... | | | |

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| **IRIDEÆ.** | | | |
| *Patersonia sericea* ... ... ... ... ... ... ... ... ... ... ... | | | |
| **AMARYLLIDEÆ.** | | | |
| *Doryanthes excelsa* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Crinum flaccidum* (Bot. Gards.) ... ... ... ... ... ... | – | – | + |
| **LILIACEÆ.** | | | |
| *Smilax glycyphylla* ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Flagellaria indica* ... ... ... ... ... ... ... ... ... ... ... | + | | |
| *Dianella revoluta* (Bot. Gards.) ... ... ... ... ... ... | – | | |
| *Eustrephus Brownii* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Stypandra glauca* ... ... ... ... ... ... ... ... ... ... | – | | |
| **JUNCACEÆ.** | | | |
| *Xerotes longifolia* ... ... | | | |
| *Xanthorrhœa australis* | | | |
| *Juncus vaginatus* ... ... | | | |
| **AROIDEÆ.** | | | |
| *Colocasia macrorrhiza* (Bot. Gards.) | | | |
| *antiquorum* (Bot. Gards.)... | | | |
| **RESTIACEÆ.** | | | |
| *Leptocarpus tenax*... ... ... ... .. | | | |
| **CYPERACEÆ.** | | | |
| *Heliocharis* ... ... ... ... ... ... ... | | | |
| *Lepidosperma concavum*... ... ... | | | |
| *Caustis pentandra* ... ... ... ... .. | | | |
| *flexuosa* ... ... ... ... ... ... | | | |
| **LYCOPODIACEÆ.** | | | |
| *Lycopodium densum* ... ... ... ... | | | |
| *Selaginella uliginosa* ... ... ... .. | | | |

### FILICES.

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| *Schizæa rupestris* ... ... ... ... ... ... ... ... ... ... ... | + | + | + |
| *Gleichenia circinata* ... ... ... ... ... ... ... ... ... .. | – | – | – |
| *dicarpa* ... ... ... ... ... . ... ... ... ... ... ... | – | – | + |
| *flabellata* ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Todea barbara* ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Hymenophyllum Tunbridgense* ... ... ... ... ... | – | | |
| *Alsophila australis*... ... ... ... ... ... ... ... ... ... | – | | |
| *Dicksonia antarctica* ... ... ... ... ... ... ... ... ... | – | | |
| *Lindsaya linearis* ... ... ... ... ... ... ... ... ... ... | + | + | + |
| *microphylla*... ... ... ... ... ... ... ... ... ... ... | + | + | + |
| *Pteris aquilina* ... ... ... ... ... ... ... ... ... ... ... | – | – | – |
| *Lomaria discolor* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Blechnum cartilagineum* ... ... ... ... ... ... ... ... | – | – | – |
| *serrulatum* ... ... ... ... ... ... ... ... ... ... .. | – | | |
| *Asplenium flabellifolium* ... ... ... ... ... ... .. | + | + | + |
| *Notholæna distans* ... ... ... ... ... ... ... . .. | – | | |

## NATURALISED PLANTS.

### LINACEÆ.

| | | | |
|---|---|---|---|
| *Linum gallicum* ... ... ... ... ... ... .. ... .. .. | – | – | – |

### LEGUMINOSÆ.

| | | | |
|---|---|---|---|
| *Melilotus parviflorus* ... ... ... ... ... . ... . | – | | |

### COMPOSITÆ.

| | | | |
|---|---|---|---|
| *Xanthium strumarium* ... ... ... ... ... ... ... ... | – | – | – |

### SOLANACEÆ.

| | | | |
|---|---|---|---|
| *Sclandra laevis* ... ... ... ... ... ... ... ... .. .. .. | – | – | – |

### VERBENENACEÆ.

| | | | |
|---|---|---|---|
| *Lantana Camara* ... ... ... ... ... ... ... ... ... ... | – | – | – |

### EUPHORBIACEÆ.

| | | | |
|---|---|---|---|
| *Euphorbia peplus* ... ... ... ... ... ... ... ... ... ... | – | | |
| *Ricinus communis* ... ... ... ... ... ... ... ... ... | – | – | – |

| | i. Alone | ii. Em. | iii. Am. |
|---|---|---|---|
| **CULTIVATED EXOTIC PLANTS.** | | | |
| **LEGUMINOSÆ.** | | | |
| *Lotus edulis* | + | + | + |
| **LILIACEÆ.** | | | |
| *Anthericum elegantissimum* | + | + | + |
| **PASSIFLOREÆ.** | | | |
| *Passiflora vespertilio* | + | + | + |
| *amabilis* | + | + | + |
| *filamentosa* | + | + | + |
| *lutea* | + | + | + |
| *suberosa* | + | + | + |

## SUMMARY.

The above list contains the names of about 300 native plants, representing sixty-five Natural Orders. Twenty-nine plants gave positive results, in which hydrocyanic acid was liberated by the natural ferment in the plant. Seven exotic plants are also recorded for the first time, as containing cyanogenetic glucosides.

The N.O. Gramineæ has been reserved for a separate paper.

[*From the Proceedings of the Linnean Society of New South Wales, 1913, Vol. xxxviii., Part 4, October 29th.*]

# HYDROCYANIC ACID IN PLANTS

## Part ii. Its Occurrence in the Grasses of New South Wales.

By James M. Petrie, D.Sc., F.I.C., Linnean Macleay Fellow of the Society in Biochemistry.

(*From the Physiological Laboratory of the University of Sydney.*)

The systematic examination of Grasses for cyanogen compounds was the direct outcome of tests made to ascertain the cause of the sudden fatalities among stock, which took place in this State about two years ago. The sheep apparently had eaten nothing besides grass, and this grass when tested was found to contain a cyanogenetic glucoside and the corresponding enzyme.

It was conceived, that at least some of the frequent deaths from unknown causes, and which are often attributed to supposed poisonous plants, might possibly be due to such grasses.

Reference to the literature on this subject shows that hydrocyanic acid in grasses, was first discovered by Jorissen, in 1884, in *Poa aquatica* Linn., and this was followed by its detection in the sorghums, in 1902 (Dunstan and Henry). Up to the present, all the cyanophoric grasses recorded are included in about 14 genera, and are given in Table i.

Some of these exotic grasses have been naturalised in this country, and among them *Brisa minor, Lamarckia aurea,* and *Poa pratensis,* are recorded by Couperot, as yielding hydrocyanic acid, when tested by him. (Journ. Pharm. Chim., 1908, 28, 542).

These three grasses growing in this State, have been examined at various seasons, and have never given positive results, neither did they contain any trace of an enzyme capable of decomposing amygdalin.

With regard to this peculiarity, we may compare the results of the Armstrongs and Horton (Proc. Roy. Soc. Lond., B.86, 1913, 265), with *Lotus corniculatus* growing in different countries. In apparently identical plants, they found that most contained both a cyanophoric glucoside and enzyme, but that in certain countries, the plants were acyanophoric. Of the latter, some were rich in enzyme, others contained only a trace. They state in explanation, that the presence of the two correlated factors mentioned is not sufficient, and that a third factor is necessary, probably one influencing concentration. It would appear then, that the conditions of concentration are unsuitable in some instances, such as in our three grasses.

Table i.

Cyanogenetic Grasses Previously Known.

*Bambusa arundinacea* Roxb., 1911,* cultivated in N.S.W.

*Briza minor* Linn., 1908, naturalised in N.S.W.

*Catabrosia aquatica* Beauv., 1908.

*Cortaderia argentea* Stapf, 1906, cultivated in N.S.W. *C. conspicua*, *C. kermesiana*, 1906.

*Elymus* spp.

*Festuca poa* Kunth, 1908.

*Holcus lanatus* Linn., 1908, naturalised.

*Lamarckia aurea* Mœnch., 1908, naturalised.

*Melica altissima*, *M. ciliata*, *M. nutans*, *M. uniflora*.

*Panicum maximum*, *P. muticum*, 1903, introduced, *P. junceum*.

*Poa aquatica* Linn., 1884; *P. pratensis* Linn., 1908, naturalised.

*Sorghum vulgare* Pers., 1902, introduced; *S. halepense* Pers., native; *S. saccharatum*, *S. tartaricum*, 1903, introduced; *S. nigrum*.

*Stipa capillata*, *S. gigantea*, *S. hystricina*, *S. leptostachya*, *S Lessingiana*, *S. tortilis*, 1906.

*Zea Mays*, 1903, naturalised.

We have now to add to the above list of cyanogenetic grasses the names of 17 more species, which are found in New South Wales,

* The dates refer to record of hydrocyanic acid.

and which are here recorded for the first time as containing a cyanogenetic glucoside and the correlated enzyme.

TABLE ii.

CYANOGENETIC GRASSES OF NEW SOUTH WALES.

*Andropogon gryllus* Linn., N.S.Wales native grass.
*halepensis* Sibth., var. *mutica*, N.S.W. native.
*sorghum* (L.) Brot., vars., introduced.
*intermedius* R.Br., N.S.W. native.
*ischæmum* Linn., introduced from N. America.
*micranthus* Kunth, N.S.W. native (scented grass).

*Anisopogon avenaceus* R.Br., N.S.W. native.

*Bouteloua oligostachya* Torr., introduced from Mexico.

*Chloris petræa* Sw., introduced.
*polydactyla* Sw., introduced from S. Amer.
*truncata* R.Br., N.S.W. native (star grass).
*ventricosa* R.Br., N.S.W. native (blue star grass).

*Cortaderia argentea* Stapf, vars. *gigantea, rosea, variegata,* S. Amer. Pampas grass, cultivated in N.S.W.

*Cyndon incompletus* Nees (Stapf), a "blue couch" grass of S Af., perhaps indig. in N.S.W.

*Danthonia semiannularis* R.Br., N.S.W. native (wallaby grass)
*racemosa* R.Br., N.S.W. native (racemed oat-grass).

*Diplachne dubia* Scribn., Mexican grass, cultivated Bathurst, Hawkesbury.

*Eleusine ægyptiaca* Pers., N.S.W. native(Egyptian finger grass).
*indica* Gærtn., N.S.W. native (crab grass).

*Leptochloa decipiens* R.Br. (Stapf), introduced, interior and coast.

NOTES ON THE GRASSES IN TABLE ii.

These twenty species were examined at various seasons, and tested for the presence of cyanogenetic glucoside and enzyme The results of the various tests are summarised below :—

*Methods.*—Cyanogenetic compounds were shown to be present in all the species, by plasmolysis of the tissues with vapour of chloroform. (1) Those classified as "very strong" changed colour within one minute, and yielded, in one case, over 0·015% total hydrocyanic acid. (2) Those marked as "strong" gave the colour change within one hour. (3) Those which required to stand 24 hours before any visible change occurred, are described as "faint."

*General Results.*—When portions of these grasses are placed in stoppered bottles, with the test paper, but without any reagents, and kept at 37° C. for 24 hours, two species only were found to evolve free hydrocyanic acid, these were *Cynodon incompletus*, and *Diplachne dubia*. The others only gave a positive result after anæsthetising.

Immersing about 10 gm. portions in boiling water does not immediately kill the enzyme; even with 2 minutes' immersion, the grass subsequently liberates hydrocyanic acid when placed in chloroform vapour, but when kept immersed for 2-5 minutes the enzyme is completely destroyed. All the species, when thus treated for 5 minutes, and found to evolve no hydrocyanic acid with chloroform vapour during 48 hours, were then mixed with emulsin, and quickly showed the colour change due to hydrocyanic acid evolution. The compounds were thus shown to be glucosides.

### *Detailed Results of the Individual Grasses.*

*Andropogon halepensis.*—This grass, which is regarded by Hackel as the original wild species from which the sorghums have sprung, is of very wide distribution, and is now considered indigenous. The reaction of the cyanogenetic glucoside was found to be maximum in January and August, *i.e.*, in the Midsummer growth and the second growth due to the late winter rains. At other times throughout the year, including the flowering period, the grass gave only a "faint" positive reaction.

| | | | |
|---|---|---|---|
| January ... | + strong. | August ... | + strong. |
| April ... | + faint. | November ... | + faint. |

No free hydrocyanic acid was evolved from the grass on keeping in a closed bottle for three days.

*Andropogon australis* has not shown the least trace of hydrocyanic acid at any time of the year.

These two grasses are the only two indigenous sorghums, syn. respectively with *Sorghum halepense* Pers., and *S. plumosum* Beauv.

*Andropogon sorghum*, vars. *vulgaris, saccharatus*.—Grown in experimental plots these grasses were tested in each month, and gave positive reactions from January to December. There was no period in which healthy growing plants were free. In only one plot growth was arrested, and the plants killed, by cold weather in June, and within a few days the tests varied from "strong" to "faint" and nil, the height being 14 inches. Dunstan and Henry found the Egyptian sorghum to lose its glucoside entirely when 14 inches high, while, on the other hand, the sorghum grown here, on the Richmond River, and also that grown in Queensland, showed the presence of glucoside when over 4 feet high.

The glucoside was present in the inflorescence, leaves, stems, and roots. The top leaves were always strongest, and especially the young uncoiled apex-leaves; the reaction diminished with the position of the leaves down the stem, and frequently the lowest leaves gave none. The stems, too, showed a gradual diminution downwards, though frequently they gave uniform reactions. In the roots the strongest reaction was often obtained from the extreme tips.

The leaves also showed a remarkable variation in enzyme, as the following summary of the results, obtained from tests on the leaves of mature plants, will show:—

i. Leaves anæsthetised, showed strong positive reaction, emulsin added—no evident change produced.

ii. Leaves anæsthetised, showed faint positive reaction, emulsin added—no evident change produced.

iii. Leaves anæsthetised, showed faint positive reaction, emulsin added—very strong positive reaction.

iv. Leaves anæsthetised, gave negative result,
emulsin added—very strong positive reaction.

v. Leaves anæsthetised, showed negative result,
emulsin added—negative result,
amygdalin added—strong positive result.

In i. and ii. class of results we have apparently an abundance of enzyme, in iii. a deficiency, and in iv. entire absence. In iv., certain leaves, chiefly the lowest on the stems, contained glucoside alone, the accompanying enzyme having entirely disappeared. In v., certain leaves are shown to contain enzyme only, without glucoside.

The mature plants when cut, and exposed to the air to dry, undergo very little change, with regard to glucoside or enzyme, during the first week. After this, the glucoside is gradually hydrolysed; but while this action is proceeding, the enzyme, too, appears to be slowly destroyed, and so it happens that sometimes it is the glucoside, at other times the enzyme, which first disappears.

*Andropogon gryllus.*—This indigenous grass never shows more than a trace of glucoside, and that only in the winter; during the hot summer weather it contains none. In autumn, the flowers and also the isolated seeds gave positive reactions.

| | | | |
|---|---|---|---|
| January | – (young and green). | August ... | + faint. |
| April | + faint. | November ... | + very faint. |

*Andropogon intermedius* and *A. ischæmum* are two native grasses, which are closely related, and in the summer months give strong reactions for a cyanogenetic glucoside.

| | *intermed.* | *ischæm.* |
|---|---|---|
| January ... ... | + strong ... ... | + strong. |
| April ... ... | + faint ... ... | + faint. |
| August ... ... | + faint ... ... | + faint. |
| November ... | + strong ... ... | + faint. |

*Andropogon micranthus.*—At no period was more than a trace of hydrocyanic acid detected, even throughout the flowering season, and during the winter months the grass was entirely free.

| | | | |
|---|---|---|---|
| January ... | + faint. | August ... | – |
| April ... ... | + faint. | November ... | + faint. |

*Bouteloua oligostachya.*—This Mexican prairie grass is growing in the neighbourhood of Tenterfield, and specimens from there growing in the Botanic Gardens, were found, at certain seasons, to react strongly for glucoside. In the autumn it entirely disappeared, to return again faintly in the rainy season, and gradually to increase in the Spring, to a maximum at Midsummer.

| | | | |
|---|---|---|---|
| January ... | + very strong. | August ... | + faint. |
| April ... | – | November ... | + strong. |

*Chloris.*—Four specimens of this grass are cyanophoric; of these two are native to N.S.Wales, viz., *C. truncata* and *C. ventricosa*, and are widely distributed over the Eastern States.

The exotic species, from which positive results were obtained, are *C. petræa* and *C. polydactyla*, and are cultivated in the Botanic Gardens.

| | January. | April. | August. | November. |
|---|---|---|---|---|
| *C. truncata* ... | + strong ... | + faint .. | – ... .. | – ... ... |
| *C. ventricosa* .. | + strong . | – . ... | + faint ... | + faint ... |
| *C. petræa* . | + faint ... | – ... .. | + faint | + very strong |
| *C. polydactyla*.. | + very strong | + very strong | + very strong | + very strong |

Samples of the native species were collected by Mr. Breakwell in Narrabri, Wagga, and Coonamble districts, from September to December, and these all gave, during this season, negative results.

*Cortaderia argentea.*—The three varieties, *gigantea, rosea, variegata*, growing in the Botanic Gardens, were tested, and also a number of specimens growing elsewhere in Sydney. All gave "strong" reactions in all seasons.

*Cynodon incompletus.*—This blue couch-grass is recorded only from E. and S. Africa, and in New South Wales from the Upper Hunter River and Forbes. It is still doubtful whether it has been introduced from S. Africa or is indigenous to Australia (Maiden, Agric. Gaz. N.S.Wales, 1912, 295).

Hydrocyanic acid was first detected in this grass in November, 1911, in a patch cultivated in the Botanic Gardens, and which had

been brought by Mr. Maiden from Aberdeen in 1907, from a spot on which cattle had died in November of that year. The cause of the fatality was associated with this grass. Samples were also obtained, through the Chief Inspector of Stock, from Scone and Muswellbrook, and these all gave strong positive reaction at this same season. A second fatality took place at Forbes, where over 100 sheep died on December 9th, 1911. This grass was recognised on the spot, and when tested gave a very strong reaction. A third fatality occurred in the same district in February, 1913; after which some sheep were isolated and fed on this grass alone, when each of them died within half an hour. A sample of this same lot was received for analysis, from the Inspector of Stock at Forbes, and gave the following result:—

| | In fresh material. | In grass dried at 100°C. |
|---|---|---|
| Free hydrocyanic acid ........ | 0·006 % | 0·008 % |
| Combined hydrocyanic acid | 0·010 % | 0·017 % |
| Total hydrocyanic acid.. | 0·016 % | 0·025 % |

The free acid was estimated by destroying the enzyme with boiling water, and distilling into standard alkali. The distillate was then titrated with silver nitrate.

The total acid was estimated by previous fermentation of the grass, and then distilling off the volatile acid.

It was calculated from the free acid figure that a sheep of 150 lbs. weight would require, for a lethal dose, to eat about 2 lbs. weight of this grass.

*Effect of drying on cut grass.*—Grass which gave a very strong reaction for hydrocyanic acid, when exposed openly to the air, showed a gradual diminution of the intensity of reaction during three weeks. At the end of this time the grass reacted only very faintly, and usually in the fourth week gave negative tests. When now, this grass was moistened, and emulsin added, it still gave negative results, but on adding amygdalin instead, a strong positive

result followed. The glucoside alone had disappeared, the enzyme was still active.

A similar result was also obtained with grass which had been air-dried for over three months.

Seasonal variations of *C. incompletus*:—

| | | | |
|---|---|---|---|
| June | ... faint. | December | ... very strong. |
| July | ... faint. | January | ... very strong. |
| August | ... very faint. | February | ... very strong. |
| September | ... faint, increasing. | March | ... strong. |
| October | ... strong. | April | ... decreasing, faint. |
| November | ... very strong. | May | ... faint. |

The author desires to express his indebtedness, and thanks to the following gentlemen, for supplies of this grass, at the various seasons:—Chief Inspector Symons, of the Stock Department; Stock Inspectors C. Brooks, of Scone, and W. G. Dowling, of Forbes; Police Inspector Nolan, of Forbes; Mr. J. H. Maiden, F.L.S.

*Other Couch-grasses.*—*Cynodon dactylon* Pers., the common couch grass of lawns was tested from various parts of the State.

*Digitaria didactyla* Willd., the Sydney blue couch, is found in certain isolated patches only, such as Hunter's Hill, Vaucluse, and Botanic Gardens. These two grasses have always given negative results for hydrocyanic acid, but in a number of instances they showed the presence of an active enzyme capable of hydrolysing amygdalin.

*Danthonia semiannularis* is generally considered one of the most valuable and nutritious of the native grasses. It gives a faint reaction for cyanogenetic compounds, but towards the end of summer it is parched and dry, and is then quite free, till the autumn rains renew the growth.

| | | | |
|---|---|---|---|
| January | ... + faint. | August | ... + faint. |
| April | ... – | November | ... + faint. |

Samples of this grass were collected by Mr. Breakwell from Narrabri, Wagga, Moree, etc., at the various seasons, and all gave similar results, when tested.

*Diplachne dubia*, a Mexican grass, cultivated in the Botanic Gardens. This is one of the strongest cyanogenetic grasses tested. It

evolves free hydrocyanic acid continually, and if placed in a stoppered bottle with the test paper, shows an intense reaction in a few minutes. The glucoside, enzyme, and free acid, are present in all parts, and throughout the whole year.

| | | | |
|---|---|---|---|
| January ... | + very strong. | August .. | + very strong. |
| April ... | + very strong. | November ... | + very strong. |

*Eleusine aegyptiaca* and *E. indica.*—These two native grasses are widely distributed, the former in the interior of New South Wales, and the latter in the coastal districts. They are very rich in cyanogenetic glucosides, all parts of the plants giving strong reactions, except in the winter.

| | *aegypt.* | *indica.* | |
|---|---|---|---|
| January ... ... ... | + | + | strong. |
| April ... ... ... | + | + | strong. |
| August ... ... ... | – | – | |
| November ... ... | + | + | strong. |

*Leptochloa decipiens.*—This exotic grass reacts energetically for cyanogenetic glucoside at all times of the year, and is strongest in Autumn and late Spring. The flowers and seeds are also very strong. It is cultivated in the Botanic Gardens and Centennial Park.

*Grasses cultivated in the Botanic Gardens.*

By the co-operation of the Director of the Gardens, Mr. J. H. Maiden, 152 different species of native and exotic grasses have been tested at four different seasons throughout the year. A number of the results were confirmed by tests on material collected by Mr. E. Breakwell, B.A., B.Sc., Department of Agriculture, in the pastoral districts and at the Government Farms.

All the specimens have been carefully examined by Mr. E. Cheel in the National Herbarium, and considerable time has been occupied in their identification. The species were checked and confirmed by Mr. Maiden, and a number of doubtful ones were referred to Kew. It will be recognised that the value of the results stated is largely dependent on the fact that the botanical names are as correct as it is possible to give them, and for this essential

part of the work much credit is due to my collaborators.

The grasses were tested in a similar manner to the plants recorded in Part i. (These Proc. xxxvii., 1912, 220), *viz.*, (1) grass in vapour of chloroform, for presence of cyanogenetic compounds and free hydrocyanic acid, (2) grass and emulsin, in case of enzyme deficient or absent, and (3) grass and amygdalin, for presence of $\beta$ enzymes.

These three tests are represented respectively by the three signs in each column.

| | Jan. | April. | Aug. | Nov. |
|---|---|---|---|---|
| *Agropyron scabrum* Beauv. | – . . | – . . | – . . | – [illegible] . |
| *Agrostis alba* Linn. | – – – | – . . | – . – | – . – |
| *stolonifera* Linn. | – – – | – . . | – . . | – . – |
| *stolonifera* Linn., var. *gigantea* | – – – | – . . | – . . | – . – |
| *verticillata* Vill. | – – – | – . . | – . . | – . – |
| *vulgaris* With. | – . – | – – – | – . . | – . – |
| *Alopecurus geniculatus* Linn. | – . – | – – – | – . – | – . – |
| *Andropogon affinis* R.Br. | – – – | – . . | – . . | – . . |
| *annulatus* Forst. | – – – | – . . | – . . | – . . |
| *australis* Spreng. | – – – | – . . | – . . | – . . |
| *bombycinus* R.Br. | – – – | – . . | – . . | – . . |
| *gryllus* Trin. | + . . | + . . | + . . | + . . |
| *halepensis* Sibth., var. *mutica* Hack. | + . . | + . . | + . . | + . . |
| *intermedius* R.Br. | + . . | + . . | + . . | + . . |
| *ischæmum* Linn. | + . . | + . . | + . . | + . . |
| *micranthus* Kunth. | + . . | + . . | – . . | + . . |
| *saccharoides* Sw., var. *barbinodis* | – – – | – . – | – – + | – . – |
| *schœnanthus* Linn. | – – – | – . . | – . . | – . . |
| *sericeus* R.Br. | – – – | – . . | – . . | – . . |
| *Anthoxanthum odoratum* Linn. | – . + | – – – | – . . | – . + |
| *Aristida ramosa* R.Br. | – – – | – . – | – – – | – . – |
| *Arundinella nepalensis* Trin. | – – – | – . – | – . – | – – – |
| *Asperella hystrix* Linn. | – – – | – . . | – . . | – . – |
| *Astrebla triticoides* F.v.M. | – – – | – . | – . + | – . – |
| *Bouteloua oligostachya* Torr. | + . . | – . . | + . | + . . |
| *Briza minor* Linn. | – . – | – . – | – . – | – . . |
| *Bromus erectus* Huds. | – – – | – . . | – . . | – . – |

| | Jan. | | | April. | | | Aug. | | | Nov. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bromus inermis* Leyss | − | − | − | − | . | . | − | . | . | − | . | − |
| *Kalmii* Gray | − | − | − | − | . | . | − | . | . | − | . | − |
| *madritensis* Linn. | . | . | . | − | . | + | − | . | − | − | . | − |
| *Pampellianus* Scribn. | − | − | − | − | . | . | − | . | . | − | . | − |
| *racemosus* Linn. | . | . | . | − | . | − | − | . | . | − | . | + |
| *tectorum* Linn. | − | . | . | . | . | . | . | . | . | . | . | . |
| *unioloides* H.B.K. | − | − | − | − | . | − | − | . | − | − | . | − |
| *Catapodium syrticum* Murb. | . | . | . | − | . | − | − | . | − | − | . | − |
| *Cenchrus australis* R.Br. | − | . | − | − | . | − | − | . | | − | . | − |
| *Chætum bromoides* | − | . | + | − | − | − | − | . | . | − | . | + |
| *Chloris gayana* Kunth. | − | − | − | − | . | . | − | . | . | − | . | − |
| *petræa* Sw. | + | . | . | − | . | − | + | . | | + | . | . |
| *polydactyla* Sw. | + | . | . | + | . | . | + | . | | + | . | . |
| *submutica* H.B.K. | − | − | − | − | . | . | − | . | . | − | . | − |
| *truncata* R.Br. | + | | . | + | . | . | − | − | − | − | − | − |
| *ventricosa* R.Br. | + | . | . | − | − | − | + | . | . | + | . | . |
| *Coix lachrymi-Jobi* Linn. | − | − | − | − | . | . | − | . | . | − | . | . |
| *Cortaderia argentea*, var. *rosea* | + | . | . | + | . | . | + | . | . | + | . | . |
| var. *gigantea* | + | . | . | + | . | . | + | . | . | + | | . |
| var. *variegata* | + | . | . | + | . | . | + | . | . | + | . | . |
| *Corynephorus canescens* Beauv. | − | − | + | − | − | + | − | . | − | − | . | − |
| *Cynodon dactylon* Pers. | − | − | + | − | . | + | − | − | − | − | . | . |
| *incompletus* Nees | + | . | . | + | . | . | + | | . | + | . | . |
| *Dactylis glomerata* Linn. | − | . | − | − | . | − | − | . | . | − | . | − |
| *Danthonia semiannularis* R.Br. | + | . | . | − | . | . | + | . | . | + | . | . |
| *racemosa* R.Br. | + | . | . | . | . | | . | . | . | . | . | . |
| *Dichelachne crinita* Hook. | − | − | − | − | . | . | − | . | . | − | . | − |
| *Digitaria didactyla* Willd. | . | . | . | . | . | . | . | . | . | . | . | . |
| *tenuiflora* Beauv. | . | . | . | − | . | − | − | . | . | − | . | − |
| *Diplachne dubia* Scribn. | + | . | . | + | . | . | + | . | . | + | . | . |
| *Echinopogon ovatus* Palis. | . | . | . | . | . | . | . | . | . | . | . | . |
| *Ehrharta calycina* Sw., var. *versicolor* | − | − | . | − | . | − | − | . | − | − | . | − |
| *Eleusine ægyptiaca* Pers. | + | . | . | + | . | . | − | . | . | + | . | . |
| *indica* Gærtn. | + | . | . | + | . | . | − | . | . | + | . | . |
| *Elymus arenareus* Linn. | − | − | − | − | . | − | − | . | . | − | . | − |
| *robustus* Scribn. | − | − | − | − | . | − | − | . | − | − | . | − |
| *virginicus* Linn. | − | − | − | − | . | . | − | . | . | − | . | − |
| *Eragrostis Brownii* Nees | − | − | − | − | . | . | − | − | − | − | . | − |
| *curvula* Nees. | − | − | − | − | . | − | − | . | . | − | . | − |
| *diandra* Steud. | − | . | − | − | − | − | − | . | . | − | . | . |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Eragrostis leptostachya* Steud | – | – | – | – | . | . | – | . | . | – | . | . |
| *major* | – | . | – | – | . | – | – | . | . | – | . | . |
| *pilosa* Beauv. | – | – | + | – | – | + | – | . | | – | . | – |
| *plana* Nees | – | – | – | – | – | – | – | – | – | – | – | – |
| *purshii* Schrad. | – | – | + | . | . | . | – | . | + | – | . | – |
| *Erianthus ravennæ* Beauv. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Festuca bromoides* Linn. | . | . | . | . | . | . | – | – | – | . | . | . |
| *duriuscula* Linn. | – | – | – | – | . | . | – | . | – | – | . | – |
| *elatior* Linn. | – | – | – | – | . | . | – | . | . | – | . | – |
| *elatior* Linn., subsp. *arundinacea* | – | – | – | – | . | . | – | . | – | – | . | – |
| *gigantea* Vill. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Hookeriana* F.v.M. | – | – | – | – | . | . | – | . | . | – | . | . |
| *ovina* Linn. | – | – | – | – | . | . | – | . | – | – | . | – |
| *ovina*, var. *tenuifolia*, Sibth. | – | – | – | – | . | . | – | . | – | – | . | – |
| *rubra* Linn. | – | – | – | – | . | – | – | . | – | – | . | – |
| *Glyceria Fordeana* F.v.M. | – | – | – | – | . | . | – | . | . | – | . | . |
| *Hæmarthria compressa* R.Br. | – | . | + | – | . | . | – | – | + | – | . | – |
| *Isachne australis* R.Br. | – | . | – | – | . | – | – | . | . | – | . | – |
| *Lagurus ovatus* Linn. | . | . | . | – | . | + | – | . | – | – | . | + |
| *Leptochloa decipiens* R.Br. (Stapf) | + | . | . | + | . | . | + | . | | + | . | . |
| *Lolium multiflorum* Lam. | . | . | . | – | – | – | – | . | . | – | . | – |
| *perenne* Linn. | . | . | . | – | . | – | – | . | . | – | . | – |
| *temulentum* Linn. | – | . | – | – | . | – | – | – | – | – | . | – |
| *Microlæna stipoides* R.Br. | – | – | – | – | . | . | – | – | – | – | . | – |
| *Miscanthus sinensis*, var. *zebrina* | – | . | – | – | . | – | . | . | . | – | . | – |
| *Oplismenus Burmanni* Beauv., var. *variegatus* | – | . | . | – | . | – | . | . | . | – | . | – |
| *Oryzopsis miliacum* Benth. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Panicum bicolor* R.Br. | – | – | – | – | – | – | – | – | – | – | . | – |
| *bulbosum* H.B.K. | – | – | + | – | . | – | – | . | + | – | . | – |
| *colonum* Linn. | – | – | + | – | . | – | . | . | . | – | . | – |
| *decompositum* R.Br. | – | – | – | – | . | . | – | . | . | – | . | – |
| *divaricatissimum* R.Br., var. *normale* Benth. | – | . | + | – | . | . | – | . | . | – | . | + |
| *flavidum* Retz. | – | – | – | – | . | . | – | . | . | – | . | – |
| *flavidum*, var. *tenuior* Retz. | – | . | – | – | . | – | . | . | . | – | . | . |
| *gracile* R.Br. | – | – | – | – | . | . | – | . | . | – | . | – |
| *leucophæum* H.B.K. | – | – | + | – | – | + | – | . | – | – | . | . |
| *marginatum* R.Br. | – | . | – | – | – | – | – | . | . | – | . | – |
| *miliare* Lam. | – | . | . | – | . | – | . | . | . | | . | . |

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| *Panicum parviflorum* R.Br. ... ... | – | – | – | – | . | . | – | . | . | – | . | . |
| *plicatum* .. .. .. .. .. .. .. .. | – | . | – | – | . | . | – | – | – | – | . | – |
| *sanguinale* Linn. .. .. .. .. .. .. | – | – | – | – | . | . | . | . | . | – | . | – |
| *strictum* R.Br. .. .. .. .. .. .. | – | . | – | – | . | . | – | – | + | – | . | – |
| *teneriffæ* R.Br. ... ... ... ... ... | – | . | – | – | . | – | – | . | . | – | . | – |
| *Paspalum dilatatum* Poir. ... ... ... | – | – | – | – | . | . | – | . | – | – | . | – |
| *distichum* Linn. .. .. .. .. .. .. | – | – | – | – | . | . | – | – | . | – | . | – |
| *læve* Michx. .. .. .. .. .. .. .. | – | – | | – | . | – | . | . | . | . | . | . |
| *paniculatum* Linn. .. .. .. .. .. | – | – | – | . | . | . | . | . | . | . | . | . |
| *platycaule* Poir. .. .. .. .. .. .. | – | – | – | – | . | . | – | . | + | – | . | + |
| *scrobiculatum* Linn. ... ... ... | – | . | – | – | . | . | – | – | + | – | . | – |
| *stoloniferum* Desv. .. .. .. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *undulatum* Poir. .. .. .. .. .. .. | – | . | – | – | – | – | – | . | . | – | . | – |
| *virgatum* Linn. .. .. .. .. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Pennisetum compressum* R.Br. .. .. | – | – | – | – | . | . | – | . | . | – | . | . |
| *latifolium* Spreng. .. .. .. .. .. | – | – | + | – | . | – | – | . | . | – | . | – |
| *longistylum* Hochst. .. .. .. .. | – | – | + | – | . | – | – | . | . | – | . | – |
| *macrorum* Trin. .. .. .. .. .. .. | – | – | – | . | . | . | – | . | . | – | . | – |
| *orientale* Rich., var. *triflorum* | – | – | – | – | – | – | – | . | – | – | . | – |
| *Phalaris bulbosa* Linn. .. .. .. .. | – | . | – | – | . | – | – | . | . | – | . | – |
| *cœrulescens* Desf. ... ... ... ... | – | . | – | – | – | – | – | . | . | – | . | – |
| *minor* Retz.... ... ... ... .. ... | . | . | . | – | . | . | – | . | . | – | . | – |
| *Poa annua* Linn. .. .. .. .. .. .. | – | . | . | – | . | – | – | – | – | – | . | – |
| *cæspitosa* Forst. ... ... ... ... ... | – | – | – | – | . | . | – | . | . | – | . | . |
| *compressa* Linn. .. .. .. .. .. .. | – | – | – | – | . | – | – | . | . | – | . | – |
| *nemoralis* Linn. .. .. .. .. .. .. | – | – | + | – | – | + | – | .. | + | – | . | – |
| *pratensis* Linn. .. .. .. .. .. .. | – | – | – | – | – | – | – | . | . | – | . | – |
| *Pollinia fulva* Benth. .. .. .. .. .. | – | – | – | – | . | . | – | – | – | – | . | – |
| *Saccharum officinarum* Linn. ... .. | – | – | – | – | . | – | . | . | . | – | . | – |
| *sara* .. .. .. .. .. .. .. .. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Secale dalmaticum* Vis. .. .. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Setaria imberbis* Roem. & Schult... | – | – | – | – | . | . | – | – | – | – | . | – |
| *Spinifex hirsutus* Labill. .. .. .. .. | – | – | – | – | . | . | – | – | – | – | . | – |
| *Sporobolus diander* Beauv. .. .. .. | – | – | – | – | . | – | – | . | . | – | . | – |
| *indicus* R.Br. .. .. .. .. .. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *virginicus* Kunth. .. .. .. .. .. | – | . | – | – | – | – | – | – | + | – | . | – |
| *Wrightiana* .. .. .. .. .. .. .. | – | . | . | – | . | . | . | . | . | . | . | . |
| *Stipa elegantissima* Labill. .. .. .. | – | . | – | – | . | . | – | . | + | – | . | – |
| *pubescens* R.Br. .. .. .. .. .. .. | – | . | – | – | . | – | – | . | . | – | . | – |
| *tenuissima* Trin. .. .. .. .. .. .. | – | – | – | – | . | – | – | . | . | – | . | + |

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| *Stipa verticillata* Trin. ... ... ... ... | – | – | – | – | . | . | – | – | + | – | . | – |
| *Themeda avenacea* .. .. .. .. .. .. | – | – | – | – | . | . | – | . | – | – | . | . |
| *Forskali* Hack. ... ... ... ... .. | – | – | – | – | . | . | – | . | . | – | . | . |
| *gigantea* Hack. .. .. .. .. .. | – | – | – | – | – | – | – | . | – | – | . | – |
| *Triodia albescens* Munro .. .. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Trypsacum dactyloides* Linn. .. .. | – | – | – | – | . | . | – | . | . | – | . | – |
| *Uniola latifolia* Michx. .. .. .. .. | – | – | + | – | . | – | – | . | . | – | . | – |
| *Zoysia pungens* Willd. ... ... ... ... | – | – | – | – | . | – | – | – | + | – | . | – |

The author desires to express his indebtedness to Professor Anderson Stuart for laboratory facilities afforded for this investigation.

[*From the Proceedings of the Linnean Society of New South Wales, 1913, Vol. xxxviii., Part 4, November 26th.*]

# NOTE ON THE OCCURRENCE OF STRYCHNICINE.

By James M. Petrie, D.Sc., F.I.C., Linnean Macleay Fellow of the Society in Biochemistry.

(*From the Physiological Laboratory of the University of Sydney.*)

*Strychnos psilosperma* is a small tree, endemic in northern New South Wales, and Queensland. Its leaves possess a bitter taste, and are found to contain the little-known alkaloid strychnicine, accompanying strychnine and brucine.

*Occurrence.*—Strychnicine was discovered by Dr. van Boorsma, in 1902.* He isolated this alkaloid from the leaves of *Strychnos nux-vomica*, detecting it even in their earliest stages. He also found it in the pulp of the ripe fruit, in the hard shell, and in the thin orange-coloured skin of the fruit. The seeds contained a trace, and sometimes none. It was also identified in the leaves of *Strychnos tieuté* of Java; and was shown to be absent from the bark and wood of both these species. In the former it is associated, in the leaves, with both strychnine and brucine, while in the latter species with strychnine only.

Van Boorsma likewise tested *Strychnos laurina* and *S. monosperma* (E. Indies), leaves and branches, both young and old, but found no strychnicine.

Since its discovery, in 1902, this alkaloid has apparently been entirely neglected. The original paper, occurring in a botanical journal, published in the Dutch East Indies, has probably not been available to all workers; and perhaps for this reason, the *Strychnos* species which have been examined, other than those mentioned, have not been tested for strychnicine.

*Separation of Strychnicine.*—The leaves of *Strychnos psilosperma* were extracted with alcohol, the solvent distilled off *in*

* Bull. de l'instit. bot. de Buitenzorg, xiv., 1902, 3.

*vacuo,* and the residue dissolved in acidulated water. From this solution, containing alkaloids, the colouring matter was removed with ether and chloroform; then, on adding a slight excess of sodium hydroxide, the alkaloids were precipitated, and extracted with chloroform. The extract was shaken with acidulated water, and back into chloroform, a number of times in succession. Finally, the chloroform was distilled off, and the residue converted into sulphates, which were then dissolved in hot water and crystallised. The alkaloids readily separated in this way, and left in the mother-liquor a small amount of brucine, and most of the glucoside loganin, which imparted to the solution its characteristic purple tint.

The sulphates of the combined alkaloids were recrystallised from water and alcohol, and this left a peculiar green fluid, which gradually changed to brown on long standing. This point was observed also by Hooper* in his examination of *S. nux-vomica* leaves, and stated by him to be due to an acid resin.

The white crystallised sulphates were next dissolved in the minimum quantity of water, and precipitated by a considerable excess of sodium hydroxide. Van Boorsma states that the strychnicine redissolves under these conditions. The precipitate which was separated by the centrifuge, consisted of strychnine, and the supernatant fluid was examined for strychnicine. On the addition of more alkali to this fluid, further deposition took place of a bulky precipitate, first white, then turning to pink, brown, and dark brown. This precipitate appeared also to be easily soluble on adding a very little water, and was removed by shaking out with chloroform. The remaining aqueous solution, and from which nothing more could be removed by chloroform, still gave a Mayer reaction when tested, and became fluorescent when acidulated; it, however, did not taste bitter. The chloroform-extract then contained that portion of the alkaloids which was not permanently precipitated by sodium hydroxide. After removal of the chloroform, and dissolving in dilute sulphuric acid, to the solution, potas-

* Pharm. Journ. xxi., 1890, 493.

sium ferrocyanide was added, in order to separate any strychnine. This ferrocyanide precipitate and filtrate were separately examined.

*Results.*—The small ferrocyanide precipitate, when extracted with ammonia and chloroform, and the latter distilled off, left a residue, which—(1) gave all the general reactions for alkaloids, (2) with sulphuric acid and bichromate did not give the characteristic colour-reaction for strychnine, (3) gave no red colouration with nitric acid. This ferrocyanide precipitate, therefore, contained an alkaloid, which was not strychnine, and not brucine.

The filtrate from the ferrocyanide was also shaken out with alkali-chloroform, the solvent removed by distillation and the residue tested: (1) It gave all the general alkaloidal reactions, (2) it did not give the strychnine colour-test with sulphuric acid and bichromate, but (3) gave a faint positive reaction with nitric acid for brucine. The ferrocyanide filtrate, therefore, also contained an alkaloid, which was not strychnine, and in which only a trace of brucine was detected.

The alkaloid in both ferrocyanide precipitate and filtrate, when dissolved in a little dilute acid, gave precipitations with Wagner and Mayer solutions, picric, phosphotungstic, phosphomolybdic, tannic acids. When treated with excess of sodium hydroxide and filtered, the solution gave with hydrochloric acid the purple colour due to strychnicine, a reaction which the discoverer states to be characteristic of this new alkaloid. Barium hydroxide in excess and the solution then acidified with hydrochloric acid, also gives the characteristic purple reaction.

*References.*—It is noteworthy that, in the literature on the Strychnos species, before van Boorsma's discovery, there are definite indications of a probable new alkaloid; for example, Shenstone (Journ. Chem. Soc. 37, 1880, 235) states, that the igasurine of Desnoix is a mixture of strychnine and brucine, with a trace of some persistent impurity. Koefoed (Chem. Zeit., Mar. 16, 1889, 78; thro. Pharm. Journ. xix., 864) shows evidence which led him to conclude, that commercial strychnine and brucine each contain two

alkaloids. Fractional crystallisation of the platinum salts gave two different compounds containing different amounts of Pt.; the molecular difference represented $CH_2$, and the author distinguished the new compound by the prefix "homo." Hooper (Pharm. Journ. xxi., 1890, 493) in his investigation of the constituents of the leaves of *S. nux-vomica,* found that potassium ferrocyanide gave only a small precipitate, but that this did not possess the properties of strychnine; it did not give the sulphuric-bichromate reaction.

*Summary.*—The alkaloid discovered by van Boorsma in 1902, in the leaves of *Strychnos nux-vomica,* and named by him, strychnicine, is identified in the leaves of the Australian endemic species, *Strychnos psilosperma.* This strychnicine is found in the mother-liquor, after separating strychnine and brucine by sodium hydroxide and crystallisation. It is only partially precipitated by ferrocyanide, on long standing at a low temperature. It is recognised by its giving all the general alkaloid reactions, by giving a negative result for strychnine with sulphuric and bichromate, and a negative brucine result with nitric acid. Its solubility in sodium hydroxide, and its colour-reaction with barium or sodium hydroxide and hydrochloric acid are characteristic.

I am indebted to Mr. F. Turner, F.L.S., for the supply of material, which was sent to him by Dr. Bancroft, from North Queensland, and to both I take this opportunity of expressing my thanks. I have also to thank Professor Anderson Stuart for laboratory accommodation and facilities.

[*From the Proceedings of the Linnean Society of New South Wales, 1916, Vol. xli., Part 1, April 26th.*]

# THE CHEMICAL INVESTIGATION OF SOME POISONOUS PLANTS IN THE N.O. SOLANACEÆ.

## PART ii. *NICOTIANA SUAVEOLENS*, AND THE IDENTIFICATION OF ITS ALKALOID.

BY JAMES M. PETRIE, D.SC., F.I.C., LINNEAN MACLEAY FELLOW OF THE SOCIETY IN BIOCHEMISTRY.

(*From the Physiological Laboratory of the University of Sydney.*)

*Nicotiana suaveolens* Lehm., the "native tobacco" of Australia, and the only endemic species, is plentiful in the interior of this State. It grows about three feet high, and is often a troublesome weed in the stock country. It is a drought-resistant plant, and spreads over large tracts of land in the dry seasons. Hence it is that, when grass and other fodder plants are withered or overrun by this weed, it is often the only green plant left available to starving animals. It is then readily eaten by stock, and, according to the reports of the owners and Inspectors, the results are variable. Though in many cases no apparent harm has followed, there is still a consensus of opinion among stockmen, that many of their losses must be attributed to this plant.

The only record of tests having been made on this species, is a paper by Dr. Bancroft (Proc. Roy. Soc. Queens., iv., 1887, p 9), in which he states that the physiological effect of the extracts on animals resembled that of extracts of true tobacco and of pituri.

The following is the account of a chemical investigation of this plant, which was undertaken to decide definitely the nature of its active principle, and also to determine whether this constituent is present in quantity sufficient to cause death.

*Extraction of active principle:* For this purpose, plants were collected in the midsummers of 1911, 1912, and 1913, chiefly from the dry North-West. Through Chief Inspector Symons, of the Stock Department, a sample was received from Narrabri. This, on its arrival, contained 37 per cent. of moisture, and consisted of leaves, stalks, and roots. The whole sample was extracted with alcohol, and the solvent afterwards removed by

distillation under diminished pressure. The extract gave all the general alkaloid reactions, and smelt strongly of tobacco. The alkaloid was completely removed from this extract by petroleum spirit (b.p. under 45°C) after making alkaline with sodium hydroxide. From this coloured solution, the alkaloid was carefully purified without loss, by shaking it into water and petroleum spirit successively, many times, and finally obtained as a colourless, aqueous solution. This solution was slightly alkaline, and possessed the odour of nicotine. It was then titrated with tenth-normal acid and alkali, and gave an equivalent of 2 c.c. of acid neutralised by the alkaloid. If this quantity be calculated as nicotine, it represents 0·0324 gm., and is 0·124 per cent. of the plant (dried at 100°).

A second sample, from the Castlereagh River, in the Coonamble district, was obtained from Mr. Breakwell, of the Department of Agriculture. This sample had been spread out to dry in the air to avoid mould in transit, and when received it contained only 9 per cent. of moisture. The whole of the material, consisting of leaves and stalks, in this case was subjected to distillation in a current of steam, the powdered plant being first mixed with 0·5 per cent. sodium hydroxide in solution, and a large excess of milk of lime. The whole of the alkaloid passed into the distillate; and the residue in the still being free from alkaloid, showed that no non-volatile alkaloid existed in the plant. The voluminous distillate contained much ammonia, which is derived from the cleavage of amido compounds, and this free ammonia was eliminated by passing a current of air through the solution for many hours. The alkaloid was next converted into oxalate, and the fluid concentrated at a low temperature to about 300 c.c. From this solution ether removed the alkaloid, and the ether extract was carefully purified and dried. The ether was then slowly removed, and the residue dried to constant weight; 0·07 gm. was obtained, which represented 0·011 per cent. of the plant-material dried at 100°C.

Another quantity was collected for me, near Picton, about 50 miles from Sydney, by Mr. E. Cheel, of the National Herbarium. This consisted of fresh, green leaves and stalks, with 72 per cent.

of moisture. The whole was distilled as before, in a current of steam, until the alkaloid was completely volatilised. The alkaloid was isolated and purified as in the last case, neutralised with excess of tenth-normal oxalic acid, and the excess determined by titration, using cochineal indicator. The result in this case gave 0·0178 gm. of alkaloid, or 0·015 per cent. of the plant (dried at 100°).

If we regard the above sample containing 72 per cent. of water as a fair average specimen of fresh material, we can express these results also in terms of the green plant, and thereby form a better idea of the amount of alkaloid in the original plant as eaten by stock. The results may then be stated:—

Amount of Alkaloid expressed as Nicotine.

| | | |
|---|---|---|
| (1) | 0·035% of fresh plant. | 0·124% of plant dried at 100°C. |
| (2) | 0·003% of fresh plant. | 0·011% of plant dried at 100°C. |
| (3) | 0·004% of fresh plant. | 0·015% of plant dried at 100°C. |

*Examination of the Alkaloid.*—The aqueous solution is alkaline to litmus, and possesses a burning taste, and the characteristic tobacco odour. The pale yellow substance, when exposed to the air, oxidises, and turns dark brown; it then possesses the nauseating odour of nicotine.

Of the salts of nicotine, the most characteristic, and the one best adapted for the identification of the alkaloid, is the picrate. Accordingly, the picrate was prepared from the aqueous solution by the addition of excess of picric acid. The dense yellow precipitate, amorphous at first, gradually assumed, on standing, the characteristic, thin, yellow, needle-shaped crystals. At the same time, pure nicotine picrate was prepared under similar conditions, and the crystals compared. Under the microscope, they were precisely alike. The crystals were washed completely with distilled water, and recrystallised three times from water, then finally dried at 100°C The melting-points were then determined together:—

| | |
|---|---|
| Picrate of N. suaveolens alkaloid ...... —m.p. | 218°C. (corrected). |
| Picrate of pure nicotine.................... | 218 |
| The two mixed together.. .. .............. | 218 |

The melting-point of nicotine picrate has been determined by Pinner and Wolffenstein as 218°C. (Ber. 24, 1891, 66).

The alkaloid of *Nicotiana suaveolens* is therefore nicotine.

For the purpose of comparison, pure nicotine tartrate (B.W.) was decomposed, and the nicotine distilled from it in a current of purified hydrogen gas. It was collected and at once sealed up in the receivers. From this colourless liquid, the nicotine picrate was prepared.

*Toxicity of the plant:*—Nicotine is probably the most violent poison known. Wynter Blyth gives the lethal dose for a human adult as about 6 mgs. In Abderhalden's "Biochemisches Handlexikon," it is stated that 5 mgs. suffice to kill a medium-sized dog in three minutes. It is evident from these data, taking even the lowest value of nicotine in the above results, that there is enough contained in one half pound of the green plant, to poison an ordinary sized sheep.

*References to the plant as a stock poison:* - Of the 80 or more species of Nicotiana, only a few are known to contain nicotine. *Nicotiana suaveolens* being limited to the Australian continent, the records of fatalities are all local. But it is referred to, also, by European authorities, such as Dragendorff in "Die Heilpflanzen," (1898) as a poisonous plant; by Greshoff in his "Monographia de plantis venenatis" as poisonous for cattle; and by Pammel ("Poisonous Plants," 1911) as poisonous to stock. It is described by F. M. Bailey, as a stock poison in Queensland, and by Professor Ewart as a feebly poisonous plant in Victoria. Mr. J. H. Maiden states that it is very deadly to all stock, and refers to many instances of poisoning of cattle, sheep, pigs, and rabbits. In his "Plants reputed poisonous to Stock," Mr. Maiden describes a sudden fatality, in 1891, of 300 healthy cattle, travelling on the great stock route through Milparinka.

*Summary.*—The results of this paper prove that *Nicotiana suaveolens* contains the extremely poisonous alkaloid nicotine, and that the nicotine is present in sufficient quantity to poison stock.

I express my thanks to Professor Sir Thomas Anderson Stuart, in whose laboratory the work was done.

# ON THE ACCURACY OF NEUMANN'S METHOD FOR THE ESTIMATION OF PHOSPHORUS.

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[*Read before the Royal Society of N. S. Wales, June 3, 1914.*]

FOR the estimation of phosphates in the presence of any metals but those of the alkalies the customary procedure entails two precipitations, each of which requires about twelve hours for completion. (1) The phosphate is precipitated as ammonium phosphomolybdate by adding a solution of ammonium molybdate containing nitric acid. (2) The precipitate of ammonium phosphomolybdate is dissolved in ammonium hydroxide and the phosphate is precipitated from it as magnesium ammonium phosphate by the addition of magnesia mixture. This latter precipitate is ignited to magnesium pyrophosphate, from the weight of which the amount of phosphate may be calculated. This method was first employed by Sonnenschein.

The tediousness of this process and the frequency with which estimations of phosphate are required for a number of purposes have led to many attempts to estimate the phosphate directly from the phosphomolybdate precipitate, either by weighing (Eggertz, Baxter, Baxter and Griffin, Chesneau), or volumetrically. These direct methods all have the drawback that there is some uncertainty as to the exact composition of the precipitate of ammonium phosphomolybdate obtained, so that although individual workers, performing their analyses under very uniform conditions, may have obtained satisfactory concordance in their results, these methods have not met with very general

acceptance for any but routine work and where great accuracy is not required.

Of the volumetric methods for the estimation of phosphate from the ammonium phosphomolybdate precipitate, those of Hundeshagen and of Grete depend on the direct titration of the phosphate against standard molybdic acid, but the majority are simple acid-alkali titrations, the ammonium phosphomolybdate being dissolved in excess of standard alkali, and the excess determined by titration with standard acid. The amount of phosphate present is obtained from the amount of standard alkali used up in the interaction with the precipitate. In addition to all the disadvantages due to uncertainties as to the composition of the precipitate, these methods are also generally faced with the difficulties attendant on an indistinct end-point. Taking the formula given to the precipitate by Hundeshagen, who was the first to investigate the conditions of formation of ammonium phosphomolybdate, the reaction which occurs with caustic soda is given by the equation:

$$(NH_4)_3.PO_4.12\,MoO_3.2\,HNO_3 + 28\,NaOH = 3NH_4OH + Na_2HPO_4 + 12Na_2MoO_4 + 2NaNO_3 + 13H_2O.$$

On titrating back the excess of acid, therefore, an indicator to which $NaH_2PO_4$ reacts acid, *i.e.*, a feebly acid indicator such as litmus or phenolphthalein, must be used. The ammonia formed in the reaction, however, will exert its usual disturbing influence on the sharpness of the end-point shown by this class of indicators, and will materially influence the accuracy of the determination. Early methods of this type are those of Thilo, Handy, and Pemberton jun.

In 1902, however, a method which showed a distinct advance on the previous alkalimetric methods was published by A. Neumann. In this method the ammonia formed in the reaction with caustic soda is eliminated by boiling before titration. Neumann therefore avoids all errors

traceable to an indistinct end-point. Neumann's method was especially developed for the analysis of organic substances and in connection with a process for the combustion of the organic matter and the conversion of the phosphorus into phosphates by means of oxidising acids. The organic substance is oxidised by heating with a mixture of equal volumes of concentrated nitric and sulphuric acids, renewed as required. The oxidation is complete when the acid mixture remains clear and almost colourless after the boiling off of all the nitric acid. Neumann calls the product obtained an "acid-ash." By this process the well known danger of loss of the phosphorus of organic compounds by volatilisation during ignition is entirely obviated. The phosphate in this acid-ash, which must not contain more than a certain maximal amount of sulphuric acid, is precipitated as ammonium phosphomolybdate in the presence of ammonium nitrate (10%) by the addition of an aqueous solution of ammonium molybdate. The precipitate is washed acid-free by decantation with ice-cold water, dissolved in excess of seminormal sodium hydroxide, the ammonia is boiled off, and the excess of alkali is determined by titration with seminormal sulphuric acid. Neumann takes the equation given above as correctly representing the reaction which occurs with the alkali, and according to this each cubic centimetre of seminormal alkali interacting with the ammonium phosphomolybdate corresponds to 1·268 milligrams of $P_2O_5$.

Plimmer and Bayliss have modified Neumann's acid-ashing process by adding a definite volume of concentrated sulphuric acid at the beginning of the oxidation process, and putting in nitric acid from time to time as required until the oxidation is complete. This avoids the difficulty of limitation of the amount of acid mixture, which, in the case of substances containing much fat and carbohydrate, such as milk, is rather a serious disadvantage. Plimmer

and Bayliss also wash the precipitate in a different way; they use suction and water at ordinary temperatures, and are able to complete the washing in five minutes. Gregersen recommends precipitating in the presence of 15% ammonium nitrate instead of 10%, and states that there is a lower as well as an upper limit to the amount of sulphuric acid which may be present in the acid-ash. He also calls attention to a point of some importance which was overlooked by Neumann, that is, that it is necessary to eliminate carbon dioxide from the solution before the final titration; neglect of this leads to errors of several tenths of a cubic centimetre in the titration.

I have only been able to find one set of control experiments on Neumann's method showing really satisfactory results; this occurs in Gregersen's paper mentioned above. Neumann's own paper gives extremely few control experiments. Another series of control experiments published by Plimmer and Bayliss shows variations amounting to as much as 5%, yet on the basis of these results the authors describe the method as extremely accurate. Donath gives a set of control estimations showing variations of the same extent, and describes the method as elegant. Mathison makes the statement that on $K_2HPO_4$ Neumann's method gave results agreeing to 1% with those obtained by the magnesia mixture method. Ehrström on the other hand states that the method sometimes gives inaccurate results for no apparent reason. In a recent paper by Haslam figures are given which go to show that in the determination of very small amounts of phosphorus (less than one milligram) Neumann's method may give results of higher accuracy than those obtainable by the usual methods of analysis. As, however, Neumann's method is one which is coming into general use for all classes of biochemica work, it seems that more detailed information as to the

errors to which the method may be subject will be of value. The present communication is an account of the errors I have met with in the use of this method, the effect of some conditions on these errors, and an attempt to locate them.

### Details of Method.

Neumann's method was first used in the present work for the analysis of milk; the modification of the acid-ashing process due to Plimmer and Bayliss was used and carbon dioxide was eliminated before the final titration. In the second series of experiments the estimations were performed on standard phosphate solutions. Here, of course, the acid-ashing process is unnecessary, but when the requisite amount of sulphuric acid is added to the solution a product is obtained closely resembling the acid-ash of an organic substance, and the subsequent treatment of the two series of estimations is the same in each case. The following is a summary of a typical estimation on milk:—

Ten cc. of milk were placed in a 500 cc. round bottomed long necked Jena glass flask, 10 cc. of concentrated sulphuric acid and 10 cc. of concentrated nitric acid were added and the whole was gently heated until the nitrogen peroxide fumes thinned off; the mixture was then cooled, another 10 cc. of nitric acid were added, and the heating resumed till the fumes thinned off again. After four similar additions of nitric acid, the heating was continued until this had all been driven off; the mixture remained clear and became almost colourless after ten minutes' further heating, indicating completion of the oxidation. The time required was about four hours. After cooling, the acid-ash was diluted with about 30 cc. of water and boiled for five minutes (to get rid of the nitric oxide formed by the decomposition of the nitrosyl-sulphuric acid produced), then made up to 100 cc. with water, 35 cc. of 50% ammonium nitrate solution were added, the liquid was brought just to the

boil, and the phosphate was precipitated by the addition of 40 cc. of 10% ammonium molybdate, the liquid being thoroughly shaken up for about one minute after the addition. The precipitation performed thus occurs in the presence of 10% ammonium nitrate at a temperature not lower than 70° – 80° C. and is complete in a few minutes. After standing for half an hour, the supernatant fluid was poured off through a thin 15 cm. filter, and the precipitate was washed four times by decantation with 150 cc. of ice-cold water each time (temperature 5° – 8° C.), the filter being filled with iced water after each washing. The final washings were neutral to litmus. The filter, containing a small quantity of the precipitate, was then added to the main bulk in the flask, some water was put in, and N/2 NaOH was run in until the precipitate was dissolved (19·0 cc. required), 6·0 cc. excess being then added (total 25·0 cc.). The solution was diluted, the filter broken up by vigorous shaking, and the ammonia boiled off. The solution was then cooled, its volume was made up to 150 cc., 6 drops of 0·5% alcoholic phenolphthalein added, and titrated with N/2 $H_2SO_4$ (6·25 cc. required), 2·0 cc. excess were added, the $CO_2$ was boiled off, and the hot solution neutralised again with N/2 NaOH (1·25 cc. required). Thus the total volume of alkali used was 25·0 + 1·25 = 26·25 cc., and of acid, 6·65 + 2·0 = 8·65 cc. The difference between these two volumes, 17·6 cc., multiplied by 1·268 gives 22·3, according to Neumann the number of milligrams of $P_2O_5$ present.

An attempt was first made to wash the precipitate by suction in the way recommended by Plimmer and Bayliss, but in every case it was found impossible to prevent visible amounts of the precipitate from passing through the filter. The precipitation was also tried in the presence of 15% ammonium nitrate according to Gregersen's directions, but

as the variations shown by the duplicate analyses given in Table I were no less than those shown by the analyses performed as described above, Neumann's proportions were reverted to. The values given are the amounts of $P_2O_5$ in 10 cc. of milk.

Table I.

*Amounts of $P_2O_5$ found in 10 cc. of milk by Gregersen's modification of Neumann's method.*

| Estimation. | Result A. | Result B. | Difference. |
|---|---|---|---|
| 1 | 24·9 mg. | 23·1 mg. | 1·8 mg. |
| 2 | 27·3 ,, | 28·6 ,, | 1·3 ,, |
| 3 | 25·8 ,, | 26·1 ,, | 0·3 ,, |
| 4 | 22·4 ,, | 22·2 ,, | 0·2 ,, |

The maximum difference between any two of the results shown on this table is 1·8 mg.; the average difference between two estimations is 0·9 mg. (Compare with Table II.)

In the series of estimations on standard phosphate solutions the method of transferring the small amount of precipitate on the filter to the flask was different; the precipitate was dissolved out with 60 cc. of 1 : 3 ammonia, and the filter then washed ammonia free, the washings being added to the flask; the ammonia is all got rid of again in the subsequent boiling with caustic soda. This procedure makes the titration rather easier, as a large amount of filter paper in the solution is apt to obscure the end-point.

## Results.

(a) *Milk.*—The following are some of the results obtained in the analysis of milk, illustrating the very variable closeness of agreement between the duplicate analyses. The figures represent the amount of $P_2O_5$ in 10 cc. of whole milk.

Table II.

*Amounts of $P_2O_5$ found in 10 cc. of milk by Neumann's method.*

| Estimation. | Result A. | Result B. | Difference. |
|---|---|---|---|
| 5 | 21·4 mg. | 21·0 mg. | 0·4 mg. |
| 6 | 19·8 ,, | 22·0 ,, | 2·2 ,, |
| 7 | 21·9 ,, | 22·5 ,, | 0·6 ,, |
| 8 | 23·9 ,, | 25·3 ,, | 1·4 ,, |
| 9 | 27·9 ,, | 26·8 ,, | 1·1 ,, |
| 10 | 21·4 ,, | 21·3 ,, | 0·1 ,, |
| 11 | 22·3 ,, | 22·3 ,, | 0·0 ,, |

The maximum difference between any two of the results in this table is 2·2 mg.; the average difference between two estimations is 0·8 mg.

(b) *Standard phosphate solution.*—The standard solutions of phosphate were prepared by dissolving 6·6 gm. of microcosmic salt in water and making the solutions up to one litre. These solutions have about the same concentration of $P_2O_5$ as milk. The solutions were standardised either (*a*) by evaporating a known volume of the solution to dryness in a weighed crucible, igniting, and weighing the sodium metaphosphate formed, or (*b*) by estimating the amount of phosphate present by the magnesia mixture method. The values obtained by the two methods agree together as closely as the individual estimations of either method, as the following figures for solution A (about 3·3 gm. of microcosmic salt per litre) show:—

Table III.

*Standardisation of Phosphate Solution.*

| Volume of solution. | Weight of $NaPO_3$ | Weight of $Mg_2P_2O_7$ | Weight of $P_2O_5$ | $P_2O_5$ in 20 cc. |
|---|---|---|---|---|
| 40 cc. | 0·0349 gm. | ... | 0·0484 gm. | 0·02420 gm. |
| 40 ,, | 0·0351 ,, | ... | 0·0487 ,, | 0·02435 ,, |
| 30 ,, | ... | 0·0574 gm. | 0·0366 ,, | 0·02436 ,, |
| 30 ,, | ... | 0·0571 ,, | 0·0364 ,, | 0·02426 ,, |
| 30 ,, | ... | 0·0576 ,, | 0·0367 ,, | 0·02440 ,, |

The following table gives the results obtained by Neumann's method for the amount of $P_2O_5$ in 10 cc. of the standard phosphate solutions. The errors vary considerably but are all positive.

Table IV.

*Amounts of $P_2O_5$ found in 10 cc. of standard solutions by Neumann's method.*

| Estimation. | Result by Neumann. | Difference from mean. | Result by weighing as | Percentage error. |
|---|---|---|---|---|
| 12 | 23·0 mg. | + 0·29 mg. | $Mg_2P_2O_7$ | + 3·1 |
| 13 | 23·3 „ | + 0·09 „ | (Soln. B.) | 4·0 |
| 14 | 22·8 „ | + 0·49 „ | ... | 2·2 |
| 15 | 23·1 „ | + 0·19 „ | 22·3 mg. | 3·6 |
| 16 | 24·0 „ | − 0·71 „ | ... | 7·6 |
| 17 | 23·7 „ | − 0·41 „ | ... | 6·2 |
| 18 | 23·1 „ | + 0·19 „ | ... | 3·6 |
| Mean | 23·29 „ | 0·34 „ | ... | 4·3 |
| 19 | 22·7 „ | + 0·64 „ | $NaPO_3$ | + 0·9 |
| 20 | 23·3 „ | + 0·04 „ | (Soln. C.) | 3·6 |
| 21 | 23·1 „ | + 0·24 „ | ... | 2·7 |
| 22 | 23·3 „ | + 0·04 „ | 22·5 mg. | 3·6 |
| 23 | 23·5 „ | − 0·16 „ | ... | 4·4 |
| 24 | 23·3 „ | + 0.04 „ | ... | 3·6 |
| 25 | 23·8 „ | − 0·46 „ | ... | 5·8 |
| 26 | 23·7 „ | − 0·36 „ | ... | 5·3 |
| Mean | 23·34 „ | 0·25 „ | ... | 3·6 |

The extreme difference between any two members of the first series of the above results is 1·2 mg., and of the second series, 1·1 mg. The average difference from the mean in the first case is 0·34 mg., or 1·5%, and in the second case, 0·25 mg., or 1·1%. The mean of these figures is 1·3%, and this we may take as the average casual error of these results. The means of the figures for the percentage difference of the two above sets of results from the standard results are 4·3 and 3·6% respectively, and the mean of these two figures is 4·0%. This value represents the average constant error of the results. We see from the table, therefore, that as a first approximation, the results obtained

by Neumann's method are 4·0% $\pm$ 1·3% high. The casual error of the results shown here is a good deal smaller than those shown by the results on milk given in Tables I and II, a fact which seems to idicate that there may be sources of error in the preliminary acid-ashing process to which the milks were submitted.

### Sources of Error.

In the estimation of phosphorus by the method of Neumann modified as described, there are, apart from the preliminary acid-ashing process, five stages at which sources of error may be sought.

1. The precipitation. It may (*a*) be incomplete, (*b*) the precipitate may not have the composition assigned to it.
2. The washing. (*a*) This may be insufficient, (*b*) the precipitate may be dissolved by the wash-water, (*c*) the precipitate may be decomposed by the wash-water.
3. The boiling off of ammonia. (*a*) It may be incomplete, (*b*) the substances present may be altered in some way.
4. The boiling off of carbon dioxide. (*a*) It may be incomplete, (*b*) the substances present may be altered.
5. The final titration. (*a*) The end point may not be satisfactory, (*b*) the value obtained will depend on the nature of the substances present.

Let us now consider the possibility of error coming in at these several stages.

1. (*a*) The completeness of the precipitation was proved by digesting the filtrate for several hours with excess of ammonium molybdate and ammonium nitrate. Mere traces only of further precipitation were ever obtained in this way, and as the precipitate contains only about 1·6% of phosphorus no appreciable error is introduced here. (*b*) At

the present stage of the work we have no grounds for stating whether the composition of the precipitate is that assumed by Neumann or not (see later).

2. (*a*) The sufficiency of the washing was proved by the neutrality to litmus of the wash-water. (*b*) By evaporating down the washings extremely slight amounts of the precipitate were found to have dissolved, but the quantity was too small to introduce any appreciable error. (*c*) It has been shown by Hundeshagen, and confirmed by Neumann, that large amounts of water cause the two loosely bound molecules of nitric acid to split off from the molecule of ammonium phosphomolybdate, a fact that was also noticed in the present work. This, however, is indicated by the washings becoming acid again, and washing was always stopped as soon as the washings became neutral.

3. (*a*) The freedom of the alkaline solution from ammonia was judged by testing the issuing steam with litmus paper. It was found necessary to boil the solution for considerably over an hour, instead of for twenty minutes, as stated by Neumann, before the issuing steam no longer reacted with litmus paper. The ammonia is therefore not readily got rid of. Bang considers this stage to be the weak point of the whole method, and recommends the removal of the ammonia as hexamethylene tetramine by the addition of formaldehyde. (*b*) We are not in a position to say whether this boiling, latterly with rather concentrated caustic soda, may not modify the substances present in some way.

4. (*a*) The acid solutions were vigorously boiled for ten minutes, so that little carbon dioxide could have remained in solution, and any error arising from this source must be very small. (*b*) With regard to any possible effect on the nature of the substances present we can again say nothing.

5. (*a*) The end-point of the titration left little to be desired, being determinable to one drop without difficulty.

This final titration was always performed on the acid solution while still nearly boiling, and although cold alkali was added, no error worth considering could be introduced in this way as the amount of alkali used was only about 1 cc. and the amount of carbonate introduced by it into the hot solution, if any, would be very small. (*b*) What has already been said about the composition of the substances in the solution applies here too.

All the errors set forth above about which we have definite information can thus only be of small amount, and of them three would tend to give high, two low results. The analysis of standard phosphate solutions showed us, however, that positive errors of considerable magnitude were invariably met with, and as all sources of error except those depending on the composition of the precipitate and the substances derived from it have been accounted for, we are forced to conclude either that the precipitate obtained has not the composition assumed, or that the reaction with the alkali does not take place according to the equation given above, or that the products formed are subsequently modified in such a way as to alter the amount of alkali combined with. These factors may also act simultaneously.

It has been shown by Baxter, Kilgore, Baxter and Griffin, Chesneau, Hissink and van der Waerden, Lagers, Artman, and by other workers, that the precipitate of ammonium phosphomolybdate as prepared by them invariably contained an amount of molybdenum in excess of that required by the formula given by Hundeshagen, $(NH_4)_3.PO_4.12\,MoO_3.2\,HNO_3$. It must be remembered that in preparing this substance Hundeshagen was careful to avoid excess of molybdic acid, whilst the precipitate obtained in the course of analysis is formed in the presence of considerable excess of molybdate. Hissink and van der Waerden, Richardson, and Artman have also shown that the presence of sulphuric

acid still further increases the amount of molybdenum found in this precipitate, the amount increasing with the quantity of sulphuric acid present until according to Hissink and van der Waerden, a maximum of 12·65 Mo for each P is reached. Richardson, and Artman state that the precipitate formed in the presence of sulphuric acid or a sulphate always contains sulphate, even after being washed till neutral. Richardson supposes that sulphuric acid may to a certain extent form a sulphomolybdate analogous to the phosphomolybdate, and which would react towards alkali like the latter. In the precipitate prepared as described above, however, I have not been able to detect more than traces of sulphate after complete washing. The precipitate was dissolved in sodium hydroxide and the ammonia boiled off. The solution was acidified with hydrochloric acid, and barium chloride was added. Richardson, and Artman simply dissolved the precipitate in nitric acid and then tested with barium chloride.

The conditions under which the precipitate of ammonium phosphomolybdate is formed in Neumann's method for the estimation of phosphorus thus seem to be particularly favourable to the appearance of a precipitate containing excess of molybdenum. I have, therefore, determined the amount of molybdenum contained in the precipitate formed under these conditions in order to discover what part of the error observed may be due to excess of molybdenum, as this would enable the precipitate to react with a larger amount of alkali than that assumed by the formula given above and therefore lead to high results in the estimations by Neumann's method.

### Molybdenum-content of precipitate of Ammonium Phosphomolybdate.

After trying several methods for the estimation of molybdenum, the method given by Brearley and Ibbotson

for the estimation of phosphorus was adopted. In this method the precipitate of ammonium phosphomolybdate is dissolved in ammonium hydroxide, the solution is nearly neutralised, and the phosphate and molybdate are precipitated together as a mixture of lead phosphate and lead molybdate by the addition of lead acetate. The phosphate is said not to be precipitated quite completely in this way, but as the lead phosphate formed amounts to only 10% of the whole precipitate the error introduced is not large. Knowing the amount of phosphate present we may calculate the weight of lead phosphate which should be formed, and by subtracting this from the total weight of the mixed precipitate we may obtain the weight of lead molybdate thrown down. The following are the details of an estimation.

The precipitate of ammonium phosphomolybdate obtained as described above from 10 cc. of standard phosphate solution was washed acid free with iced water and dissolved in ammonium hydroxide, the solution was made up to 200 cc. and divided into two equal parts, each part being then treated independently. The ammonia was nearly neutralised with hydrochloric acid, about 20 gm. of ammonium chloride were added, the solution was heated to boiling, and 200 cc. of a boiling solution of lead acetate and acetic acid (16 cc. 50%, saturated, lead acetate and 16 cc. of glacial acetic acid made up to 1000 cc.) were poured in. A dense white precipitate immediately formed, and the boiling was continued for ten minutes to ensure that the precipitate became granular. The precipitate is finely divided and very heavy, but when prepared as described it filters easily. The precipitate was washed free from chlorides with hot water and ignited with the filter in a muffle, very high temperatures being avoided as the precipitate is fusible.

Each precipitate obtained thus contains the equivalent of 11·28 mg. of $P_2O_5$ (standard solution D). We see from the formula of Hundeshagen for the ammonium phosphomolybdate that for each molecule of $Pb_3(PO_4)_2$ 24 molecules of $PbMoO_4$ should be formed. The weight of lead phosphate corresponding to the above amount of $P_2O_5$ is $0·01128 \times 811/142 = 0·0644$ gm. ($P_2O_5 = 142$, $Pb_3(PO_4)_2 = 811$); the weight of lead molybdate formed at the same time should be $0·01128 \times 24 \times 367·1/142 = 0·699$ gm. ($PbMoO_4 = 367·1$). The total weight of the precipitate should therefore be $0·0644 + 0·699 = 0·7634$ gm. The weights of the precipitates of lead phosphate and lead molybdate actually obtained are given in the following table:—

Table V.

*Weights of lead phosphate and lead molybdate equivalent to* 11·28 *mg. of* $P_2O_5$.

| Phosphomolybdate precipitate. | Weight of Lead Salts from Portion A. | Weight of Lead Salts from Portion B. | Mean of Two Results |
|---|---|---|---|
| 27 | 0·8075 gm. | 0·8048 gm | 0·8062 gm. |
| 28 | 0·8048 „ | 0·8049 „ | 0·8049 „ |
| 29 | 0·8085 „ | 0·8050 „ | 0·8067 „ |
| 30 | 0·8118 „ | 0·8095 „ | 0·8107 „ |

The mean weight for the whole series is 0·8071 gm. If 0·0644 gm., the weight of the lead phosphate formed, be subtracted from this we get 0·7427 gm. instead of 0·699 gm. as the weight of the lead molybdate formed. This number is 6·25% in excess of that required by the formula of ammonium phosphomolybdate used by Neumann, and instead of $(NH_4)_3.PO_4.12\ MoO_3.2\ HNO_3$ would give us $(NH_4)_3.PO_4.12·75\ MoO_3.2HNO_3$. This result is not far from that of Hissink and van der Waerden mentioned above; they found the molecular proportion of $MoO_3$ to be 12·65. Assuming the excess of molybdenum to be present as molyb-

date, each formula weight of the precipitate containing the proportion of molybdenum found in the present case should require for its neutralisation 29·5 mols of NaOH instead of 28 as assumed by Neumann, so that the results calculated by means of Neumann's factor would be $(29{\cdot}5/28 - 1)\ 100 = 5{\cdot}2\%$ too high. This excess of molybdenum is therefore sufficient to account for the high results shown in Table IV. The error of these results is $+ 4\% \pm 1{\cdot}3\%$.

### Influence of some conditions on the Error.

The influence of the following conditions upon the error of the results obtained in the estimation of phosphorus by Neumann's method have been observed:—

1. Amount of phosphate estimated.
2. Rate of addition of precipitant.
3. Length of time between precipitation and filtration.
4. Temperature of precipitation.

1. *Amount of Phosphate estimated.*—Forty cc. of 10% ammonium molybdate solution are stated by Neumann to be a suitable amount for the precipitation of any quantity of $P_2O_5$ between two or three milligrammes and sixty milligrammes. As, however, errors had already been encountered in the use of Neumann's method, three series of estimations were performed on different amounts of standard phosphate solution to ascertain whether these errors remained about the same size or depended upon the amount of phosphate precipitated. The proportions of the reagents used for the precipitation were those given previously; the amounts of sodium hydroxide used to dissolve the precipitates were, of course, increased in proportion to the amount of phosphate present, but the procedure was otherwise as described above. The following are the results obtained:—

Table VI.

*Influence of amount of phosphate estimated on error of Neumann's method.*

| Estimation. | $P_2O_5$ present. | $P_2O_5$ found. | Percentage Error. | Deviation from Mean. |
|---|---|---|---|---|
| 31 | | 51·0 mg. | + 14·3 | + 0·6 mg. |
| 32 | | 50·3 „ | 12·7 | − 0·1 „ |
| 33 | 44·5 mg. | 50·0 „ | 12·1 | − 0·4 „ |
| 34 | | 49·9 „ | 11·9 | − 0·5 „ |
| Mean | | 50·4 „ | 13·2 | |
| 12 | | 23·0 „ | + 3·4 | 0·0 „ |
| 13 | | 23·2 „ | 3·8 | + 0·2 „ |
| 14 | 22·3 mg. | 22·8 „ | 2·2 | − 0·2 „ |
| 15 | | 23·1 „ | 3·6 | + 0·1 „ |
| Mean | | 23·0 „ | 3·4 | |
| 35 | | 11·4 „ | + 0·9 | − 0·1 „ |
| 36 | | 11·7 „ | + 3·5 | + 0·2 „ |
| 37 | 11·25 mg. | 11·7 „ | + 3·5 | + 0·2 „ |
| 38 | | 11·2 „ | − 0·9 | − 0·3 „ |
| Mean | | 11·5 „ | + 1·8 | |

These results show that the error increased rapidly with the amount of phosphate estimated. For 44·5 mg. of $P_2O_5$ the average error is 13·2%, for 22·3 mg. it is 3·4%, for 11·25 mg. it is 1·8%. The results for 11·25 mg. of $P_2O_5$ are peculiar as among them there is one with a negative error. The percentage error of these results shows a considerable variation, but the actual differences of the results from the mean value show that the absolute error is no greater than those shown by the other series of estimations.

2. *Rate on addition of Precipitant.*—The rate of addition of the precipitant is stated by Baxter and Griffin and by Artman to exert a marked influence on the excess of molybdenum carried down by the precipitate of ammonium phosphomolybdate; rapid addition of the ammonium molybdate leads to the appearance of a precipitate containing more molybdenum than is present in the precipitate formed

by the slow addition of the ammonium molybdate. This effect is ascribed to the occurrence of local excess of the reagent when the latter is added quickly. The following are the results obtained when two, three, five, and ten minutes were the respective times taken to add the precipitant to the phosphate solution. The solution was thoroughly shaken while the precipitant was being added.

Table VII.

*Influence of rate of addition of precipitant on error.*

| Estimation. | Precipitant added in. | $P_2O_5$ found. | $P_2O_5$ present. | Error, per cent. |
|---|---|---|---|---|
| 39 | 10 min. | 22·8 mg. | | + 1·2 |
| 40 | 5 „ | 23·8 „ | | 5·8 |
| 41 | 3 „ | 23·8 „ | 22·5 mg. | 5·8 |
| 42 | 2 „ | 23·2 „ | | 3·0 |
| | poured in | 23·6 „ | | 5·0 |

As long as the time taken to add the precipitant remains less than five minutes, therefore, no certain diminution of the positive error is observed. When the precipitant is added, in ten minutes, there is a considerable diminution of the error, but as the solution has by this time cooled down about 20° C., this diminution is due to incomplete precipitation and not to any decrease in the excess of molybdenum due to the slow addition of the ammonium molybdate (*vide infra*).

3. *Length of time between filtration and precipitation.*—Baxter and Griffin concluded from their experiments that the excess of molybdenum in the precipitate of ammonium phosphomolybdate obtained by them was due to the occlusion of a mixture of ammonium molybdate and molybdic acid, and showed that this occlusion apparently took place in two stages, (1) during the precipitation, (2) while the precipitate, already formed, lay in contact with the mother liquor. They therefore advise that the precipitate be filtered off as soon as is compatible with complete

precipitation. In Neumann's method the length of time for which the precipitate of ammonium phosphomolybdate remains in contact with the mother liquor is not long, about thirty minutes, so, as will be seen from the following experiments, this factor is not likely to be the source of any considerable error. Two pairs of phosphate estimations were carried out by Neumann's method on 20 cc. portions of standard phosphate solution, the precipitates in one case being filtered off after having stood under the mother liquor for twenty minutes, in the other case being left in contact with the mother liquor for three days. The following are the results obtained:—

Table VIII.

*Influence of length of time between precipitation and filtration on error.*

| Estimation. | Stood for | $P_2O_5$ found. | $P_2O_5$ present. | Error, per cent. |
|---|---|---|---|---|
| 33 | 20 min. | 50·0 mg. | | +12·1 |
| 34 | 20 „ | 49·9 „ | | 11·9 |
| | | | 44·6 mg, | |
| 31 | 3 days | 51·0 „ | | 14·3 |
| 32 | 3 „ | 50·3 „ | | 12·7 |

The increase in the error of the results given by the precipitates which have stood the longer time in contact with the mother liquor is within the experimental variations to which the method is subject, so that, contrary to what Baxter and Griffin found in their case, here variations in the length of time of contact between precipitate and mother liquor do not affect the composition of the precipitate.

4. *Temperature of precipitation.*—Baxter states that the temperature of precipitation has an important influence on the excess of molybdenum carried down by the precipitate of ammonium phosphomolybdate. When the precipitation occurred at room temperature, Baxter found an excess of about 1% of molybdenum in the precipitate; in the pre-

cipitate obtained at 50° – 60° C. the excess of molybdenum was about twice as great. Chesneau also calls attention to the effect of temperature on the composition of this precipitate. He states that above 65° – 70° C. ammonium tetramolybdate—$(NH_4)_2O.4\,MoO_3$—is formed in a solution of ammonium molybdate, and that it is this substance which is carried down by the precipitate of ammonium phosphomolybdate. Many other authors state that at high temperatures molybdic acid is thrown down from solutions of ammonium molybdate, and that the precipitate of ammonium phosphomolybdate formed is contaminated with this. Precipitation at as low a temperature as possible is therefore generally advised. With the proportions of the reagents used by Neumann, however, it was not found possible to bring about precipitation within reasonable time at low temperatures. When the solutions were kept at room temperature no sign of precipitation appeared even after standing for two days. When the reagents were mixed at 40° C. and maintained at this temperature, only partial precipitation had occurred after four hours. Even at 60° – 70° C. the precipitation was by no means complete in half an hour. It was therefore found necessary, in order to ensure complete precipitation, to adhere to the temperature of precipitation set down by Neumann.

### Summary.

1. The values obtained in the estimation of phosphate by Neumann's method were always high, the error increasing with the amount of phosphate estimated. For 22 mg. of $P_2O_5$ the mean error was + 4%.

2. The source of this error is an excess of molybdenum carried down in the precipitate of ammonium phosphomolybdate.

3. The error does not depend on the rate of addition of the precipitant.

4. The error is independent of the time of contact between the precipitate and the mother liquor.

5. The error cannot be reduced by lowering the temperature of precipitation, as this leads to incomplete precipitation.

In conclusion I wish to express my thanks to Professor Anderson Stuart, in whose laboratory this work was done, and to Assistant-Professor Chapman for his advice and encouragement.

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NATURE OF DEPOSIT OBTAINED FROM MILK.

# On the NATURE of the DEPOSIT obtained from MILK by SPINNING in a CENTRIFUGE.

*(Preliminary Communication.)*

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[*Read before the Royal Society of N. S. Wales, July 1, 1914.*]

When milk is kept in a sterile condition for long periods of time (several years), a white deposit is observed to collect on the bottom of the containing vessel. Salkowski (1900) regards the deposit so obtained as precipitated caseinogen, while Langlois (1913) considers it to be tricalcium phosphate. Preti (1907) has determined the ash, calcium, and phosphorus of the deposit obtained in this way, and found 32·11% ash, 10·7% calcium, 4·33% phosphorus, and on the basis of these results regards the deposit as a mixture of tricalcium phosphate and a calcium compound of caseinogen. Neither Salkowski nor Preti came to a conclusion as to whether the appearance of this deposit was due to purely physical phenomena, whether it was due simply to the action of gravity on suspended matter in milk, or whether it was due to traces of rennin, or to the occurrence of slow chemical changes.

When milk is spun in a centrifuge, Barthel (1910) observed that a deposit similar to the above is obtained in the centrifuge tubes; he considers the deposit to be a mixture of calcium phosphate and casinogen. In this case, as the time required to obtain the deposit is quite short, the action of traces of rennin or of slow chemical changes is practi-

cally excluded, and the deposition must be due entirely to the action of centrifugal force on suspended matter in the milk. Indeed, I have observed that, if the spinning be continued long enough, part of the milk may be almost freed from suspended matter, and a zone of clear greenish-yellow milk plasma makes its appearance below the layer of fat on the surface. See also Lachs and Friedenthal (1911).

Filtration of milk through porcelain also separates the suspended matter from it, the porcelain allowing through only a clear filtrate. A doubt exists, however, as to whether a purely physical separation is affected in this way (Raudnitz, 1903). Porcelain has been shown by Hermann (1881) to possess the power of precipitating caseinogen from milk, and almost as clear a filtrate is obtained by stirring milk with powdered porcelain and then filtering as by forcing it through the pores of a Chamberland filter-candle.

In spinning milk in the centrifuge, on the other hand we have a purely physical means of separating some of the suspended matter from it, a means which will only separate substances which already exist in suspension in the milk. Very few data with regard to the character and mode of deposition of the substance obtained from milk in this way appear to be available, although a study of this substance is likely to give some definite information as to the physical state and chemical composition of the compounds existing in suspension in milk. Alson (1908) isolated what he considered to be a new protein from this deposit.

The present communication is an account of the preliminary examination of the deposit obtained from milk by spinning it in a centrifuge. The following points have been dealt with :—

1. Effect of removal of the deposit on the superfluid.
2. Rate of deposition.
3. Ash of the deposit; its variation with the time of spinning.
4. Amount of calcium and phosphorus in the ash of the deposit.
5. Amount of nitrogenous and non-nitrogenous organic matter in the deposit.
6. Solubility of the deposit in water.

**1. Effect of removal of the deposit on the superfluid.**

Moore and Roaf (1908) have obtained results which indicate that electrolytes in solution may become associated with a colloid present in such a way that, although their effect on the freezing point of the solution is not altered, their conductivity is very considerably reduced, and they are withdrawn from the solution when the colloid is removed. It was thought, therefore, that some such effect might be observable in the present case, and that the removal of suspended colloidal substance from the milk might also mean the removal of some dissolved matter. A series of determinations of the freezing point was therefore made on milks before and after the removal of different amounts of suspended matter. These determinations of the freezing point were made in a glass vessel without an air mantle. The tube containing the liquid to be frozen dipped directly into a cooling bath of ice and salt at a temperature of $-2°$ to $-3°$ C. (not lower), both the bath and the liquid to be frozen being kept thoroughly stirred. In this way a determination of the freezing point could be made in less than ten minutes and the agreement between separate determinations on the same liquid was satisfactory, as the following figures show:—

*Freezing points of water and of milk.*

| Liquid. | Experiment. | Freezing Point. | Supercooling. | Bath temp. |
|---|---|---|---|---|
| Water | 1 | 2·700 | 1·2 | – 2·5° C. |
| | 2 | 2·700 | 1·1 | 2·5 |
| | 3 | 2·701 | 0·5 | 2·5 |
| Milk | 1 | 3·252 | 2·0 | – 3·0 |
| | 2 | 3·251 | 2·0 | 3·0 |
| | 3 | 3·251 | 2·0 | 3·0 |

The absence of the air-jacket thus does not affect the precision with which the freezing point can be determined.

The following are the results obtained on milks from which different amounts of suspended matter had been removed :—

Table I.

*Effect of removal of suspended matter on freezing point of milk.*

| Milk. | Weight of Deposit. | Freezing Point. | Zero. | Depression. | Acidity. |
|---|---|---|---|---|---|
| 31 | ... | 3·211 | 2·669 | 0·542 | ... |
| | 0·0545 gm. | 3·212 | | 0·543 | |
| | 0·0936 „ | 3·216 | | 0·547 | |
| | 0·1138 „ | 3·220 | | 0·551 | ... |
| 32 | ... | 3·224 | 2·669 | 0·555 | 19·6 |
| | 0·0544 „ | 3·226 | | 0·557 | |
| | 0·0830 „ | 3·266 | | 0·557 | 19·4 |
| 33 | ... | 3·221 | 2·669 | 0·552 | 19·4 |
| | 0·0224 „ | 3·222 | | 0·553 | |
| | 0·0487 „ | 3·219 | | 0·550 | |
| | 0·0940 „ | 3·222 | | 0·553 | |
| | 0·1030 „ | 3·227 | | 0·558 | 19·6 |
| 34 | ... | 3·251 | 2·700 | 0·551 | 19·2 |
| | 0·0688 „ | 3·241 | | 0·541 | |
| | 0·0598 „ | 3·249 | | 0·549 | |
| | 0·0766 „ | 3·247 | | 0·547 | |
| | 0·1016 „ | 3·250 | | 0·550 | 20·2 |

From these figures it will be seen that there is no definite diminution in the depression of the freezing point after the removal of various amounts of suspended matter from milk, indeed there seems to be a tendency for the depression of the freezing point to increase eventually. Any effect due to the removal of adsorbed electrolytes in the deposit is therefore within the experimental error in the present case.

It was thought that the tendency for the depression of the freezing point to increase might be due to an increase in the number of particles present in solution brought about by the souring of the milk, by the breaking down of lactose into lactic acid. The splitting of lactose takes place in two main stages, (1) it is hydrolysed by lactase into glucose and galactose, (2) the hexoses thus formed are converted into lactic acid. Each molecule of hexose gives rise to two molecules of lactic acid, so that in all four molecules of lactic acid may be derived from one molecule of lactose. These reactions are represented by the following empirical equations:—

| | | | |
|---|---|---|---|
| (1) | $C_{12}H_{22}O_{11}$ | = | $2\ C_6H_{12}O_6$ |
| | (lactose) | | (glucose and galactose) |
| (2) | $2\ C_6H_{12}O_6$ | = | $4\ C_3H_6O_3$ |
| | (hexose) | | (lactic acid) |

Milk is approximately a 5% or 0·15 N solution of lactose. If the increase of the acidity of milk during souring be due to the formation of lactic acid, then each extra cubic centimetre of N/10 alkali required to neutralise 100 cc. of milk after the onset of souring will correspond to the splitting up of $0{\cdot}0001 \times 100/(0{\cdot}015 \times 4) = 0{\cdot}17\%$ of the lactose present. The value of the depression of the freezing point for milk ($-0{\cdot}55^\circ$ C.) shows it to contain a number of dissolved particles equal to that in a 0·3 N solution. We have just seen, however, that milk is a 0·15 N solution of

lactose, the value of the depression of the freezing point for the concentration of lactose in milk is therefore $-0{\cdot}225°$. When $0{\cdot}17\%$ of the lactose in milk breaks up into lactic acid the number of particles in solution is increased by three times that amount (neglecting the ionisation of the lactic acid) since for each molecule of lactose which disappears, four molecules of lactic acid are formed. The breaking up of this fraction of the lactose should therefore cause an increase of the depression of the freezing point due to this substance of $0{\cdot}51\%$, that is, from $0{\cdot}225°$ to $-0{\cdot}2263°$. Each additional cc. of N/10 alkali required to neutralise 100 cc. of milk undergoing souring should therefore correspond to an increase of the depression of the freezing point of $0{\cdot}0013°$. This value is a maximal figure, as in calculating it we have assumed that the whole of the lactose which breaks up forms lactic acid, actually, however, some of the lactose breaks up in other ways.

The acidities of samples of the milks being spun in the centrifuge were therefore determined at the beginning and at the end of the spinning to ascertain whether the tendency of the depression of the freezing point to increase might be attributed to an increase of the acidity of the milk. The samples for the determination of the acidity were kept under the same conditions as those being spun in the centrifuge. The acidities were determined by titrating 25 cc. of the undiluted milk, containing 2 cc. of $0{\cdot}5\%$ phenolphthalein as indicator, with N/10 NaOH to the first distinct pink colouration. The acidities shown in the table are expressed as the number of cc. of N/10 alkali required to neutralise 100 cc. of milk. The greatest increase of acidity occurring during the course of the spinning is seen to be 1 cc. of N/10 alkali in 100 cc. of milk, and as this corresponds to an increase of only $0{\cdot}0013°$ in the lowering of the freezing point it may be said that the alteration

of the freezing point of the milk due to the splitting up of lactose is negligible in the present case.

The effect of the removal of different amounts of suspended matter from milk by spinning in the centrifuge on the acidity of the liquid remaining has also been determined.

Table II.

*Effect of removal of varying amounts of suspended matter on the acidity of the remaining milk.*

| Milk. | Time Spun. | Acidity. |
|---|---|---|
| 44 | ... | 17·6 |
| | 1 hour | 16·95 |
| | 2 ,, | 17·25 |
| | 3 ,, | 16·95 |
| 45 | ... | 18·4 |
| | 1 hour | 17·45 |
| | 2 ,, | 17·9 |
| | 3 ,, | 18·1 |

The amount of substance removed from the milk by spinning for periods up to three hours (about 0·1 gm.) has therefore very little effect on the acidity of the milk. The amount of substance removed from the milk in this time is about 1/14 of the solids not fat of milk. Removal of the whole of the suspended matter of milk by filtration through porcelain has been shown by Professor Chapman (1908) to reduce the acidity of milk to one-third of its original value.

### 2. Rate of Deposition.

The milk was spun in the present experiments at 2000 revolutions per minute in flat-bottomed cylindrical glass tubes 14 cm. deep and containing 100 cc. The distance of the bottom of the centrifuge tubes from the axis of the centrifuge was 22 cm. The deposit forms a fairly coherent layer on the bottom of the vessel, from which the superfluid can be poured off without disturbing the deposit. The weight of a deposit was determined by transferring it to a

porcelain dish with water, evaporating to dryness over a water bath, and drying to minimal weight in an air oven at 100° C. It was not found possible to get the deposits to constant weight, as the weight after decreasing for a time then began to increase. The heating was therefore continued until this increase of weight began, the minimal weight being taken as the weight of the dry deposit. Even at the temperature of the water bath these deposits became quite brown. The following table shows the weights of deposit obtained after spinning the milk for various periods and the rate of accumulation of the deposit over these periods. The rate of deposition is expressed in milligrams per minute per 100 cc. of milk.

Table III.—*Rate of Accumulation etc. of Deposit from Milk.*

| Milk. | Volume. | Time Spun. | Weight of Deposit. | Increment. | Rate of Deposition. |
|---|---|---|---|---|---|
| 19 | 400 cc. | 30 min. | 0·2568 gm. | ... | 2·140 |
| | | 120 „ | 0·6975 „ | 0·4407 gm. | 1·224 |
| | | 180 „ | 1·0125 „ | 0·3150 „ | 1·321 |
| | | 210 „ | 1·1900 „ | 0·1775 „ | 1·521 |
| 22 | 400 cc. | 60 min. | 0·2700 gm. | ... | 1·125 |
| | | 135 „ | 0·5208 „ | 0·2508 gm. | 0·838 |
| | | 195 „ | 0·7259 „ | 0·2051 „ | 0·854 |
| | | 225 „ | 0·9015 „ | 0·1756 „ | 1·462 |
| 23 | 400 cc. | 60 min. | 0·2933 gm. | ... | 1·222 |
| | | 150 „ | 0·5787 „ | 0·2854 gm. | 0·792 |
| | | 210 „ | 0·7942 „ | 0·2155 „ | 0·898 |
| | | 270 „ | 1·0162 „ | 0·2670 „ | 1·026 |
| 24 | 300 cc. | 60 min. | 0·2642 gm. | ... | 1·468 |
| | | 120 „ | 0·4264 „ | 0·1604 gm. | 0·892 |
| | | 180 „ | 0·5791 „ | 0·1555 „ | 0·859 |
| | | 240 „ | 0·7432 „ | 0·1632 „ | 0·907 |

This table shows that there are considerable variations in the rates at which the deposits fall in different milks. Other factors being equal, this points to a difference in the size of the suspended particles in different milks. It will

also be seen that the first portion of the deposit comes down at a rate a good deal greater than that of the succeeding portion. The rate of deposition decreases to a minimum and then begins to rise again during the course of about four hours' spinning. In one case the final rate of deposition was even greater than the first rate of deposition, but as a rule the rate of deposition, after passing through the minimum, did not rise as high as the first rate in the time for which the spinning was continued; it might do so if the spinning were continued longer. There is a variation in the ash-content of the deposit in the opposite direction to the variation in the rate of deposition (see below).

### 3. Ash-content of the Deposit.

The ash of the deposits obtained from milk as described above varies somewhat from one milk to another. The ashing was performed in a muffle furnace; the rear only of the muffle was heated, the porcelain dish containing the deposits being gradually moved from the mouth of the muffle to the hotter parts. As the deposit formed a thin layer on the bottom of the dish, the ashing was very rapid and complete. The following table gives the ash-contents of a series of these deposits.

Table IV.—*Ash-content of Centrifuge-deposit from Milk.*

| Milk. | Weight of Deposit. | Weight of Ash. | Percentage of Ash. |
|---|---|---|---|
| 4 | 0·4457 gm. | 0·0310 gm. | 6·94 |
| 6 | 1·4041 ,, | 0·1001 ,, | 7·13 |
| 9 | 0·6275 ,, | 0·0618 ,, | 9·85 |
| 10 | 0·5304 ,, | 0·0431 ,, | 8·12 |
| 12 | 1·5251 ,, | 0·1157 ,, | 7·89 |
| 13 | 1·0551 ,, | 0·0913 ,, | 8·65 |
| 15 | 0·5594 ,, | 0·0452 ,, | 8·09 |
| 17 | 0·6052 ,, | 0·0503 ,, | 8·32 |
| 22 | 0·3433 ,, | 0·0297 ,, | 8·65 |
| 35 | 0·2070 ,, | 0·0180 ,, | 8·70 |
| 37 | 0·1084 ,, | 0·0107 ,, | 9·87 |
| 38 | 0·1286 ,, | 0·0122 ,, | 9·48 |
| 39 | 0·1339 ,, | 0·0120 ,, | 8·97 |
| 41 | 0·3634 ,, | 0·0247 ,, | 6·80 |
| 42 | 0·2725 ,, | 0·0192 ,, | 7·04 |

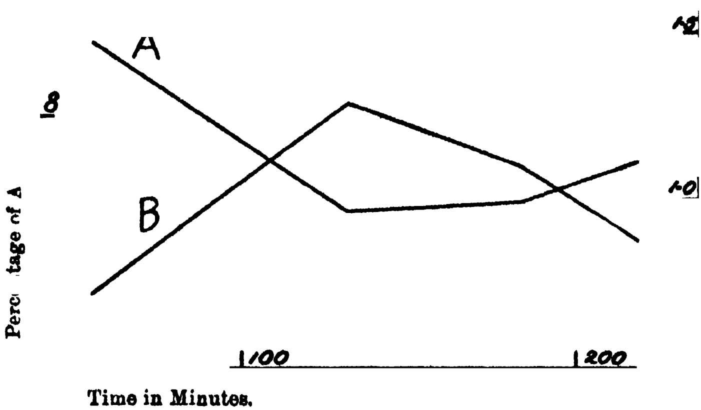
It will be seen from the preceding table that there is considerable variation in the ash-content of these deposits. The extreme values for the percentage of ash in the deposits being 6·80% and 9·87%. As will be seen below this variation is to be attributed in part to differences in the times for which the milks were spun to obtain the deposits.

*Variation of ash-content of deposits with time of spinning.*—Not only are there differences between the ash-contents of the deposits from different milks, but deposits from the same milk show different percentages of ash according to the time for which the milk is spun before collecting the deposit. Samples of deposit after various periods of spinning were got by stopping the centrifuge at the appropriate times, pouring the superfluid off the deposit into a clean tube, and putting this on to spin again to obtain the deposit corresponding to that coming down at the later period. The following table shows the variation of the percentage of ash of the deposit with the length of time for which the milk is spun.

TableV – *Variation of percentage of ash of deposit with time of spinning.*

| Milk. | Period. | Wt. of Deposit. | Weight of Ash. | Percentage Ash. |
|---|---|---|---|---|
| 19 | 30 min. | 0·2568 gm. | 0·0177 gm. | 6·89 |
| | 120 „ | 0·4407 „ | 0·0349 „ | 7·92 |
| | 180 „ | 0·3150 „ | 0·0230 „ | 7·30 |
| | 210 „ | 0·1775 „ | 0·0108 „ | 6·08 |
| 22 | 60 „ | 0·2700 „ | 0·0231 „ | 6·24 |
| | 135 „ | 0·2508 „ | 0·0203 „ | 8·09 |
| | 195 „ | 0·2051 „ | 0·0153 „ | 7·46 |
| | 225 „ | 0·1756 „ | 0·0115 „ | 6·55 |
| 23 | 60 „ | 0·2933 „ | 0·0250 „ | 6·36 |
| | 150 „ | 0·2854 „ | 0·0200 „ | 7·71 |
| | 195 „ | 0·2051 „ | 0·0183 „ | 8·49 |
| | 270 „ | 0·2670 „ | 0·0227 „ | 8·50 |
| 24 | 60 „ | 0·2642 „ | 0·0220 „ | 8·32 |
| | 120 „ | 0·1604 „ | 0·0137 „ | 8·54 |
| | 180 „ | 0·1545 „ | 0·0117 „ | 7·57 |
| | 210 „ | 0·1632 „ | 0·0130 „ | 7·97 |

From this table we see that the ash-content of the first portion of the deposit is always lower than that of the following portion. The ash-content then tends to decrease again, although in one case there is a continuous increase. We may therefore say that the ash-content of the deposit varies roughly inversely as its rate of deposition. The accompanying curves have been plotted from the means of the results shown in Tables III and V. Curve *A* has been obtained by plotting time as abscissa and rate of deposition as ordinate. In curve *B* time is the abscissa and percentage of ash of the deposit the ordinate. The curves show clearly the inverse relationship between ash and rate of deposition.




Curves showing variation with Time of Spinning, (A) of Rate of Deposition, in mg. per minute per 100 cc. of milk, (B) of Pecentage of Ash in Deposit.

The general form of the curves seems to point to the existence in milk of at least three different substances in suspension: (1) A substance of lower ash-content which comes down first. (2) A substance of higher ash-content which comes down second. (3) A substance of lower ash-content again which comes down third. There are slight

indications that there may be another substance of higher ash-content yet which comes down after this. The data are as yet, however, not sufficient to admit of any definite inference being drawn from them.

### 4. Amount of Calcium and Phosphorus in the Deposit.

*Methods of Analysis.*—The dried deposits were ashed in a muffle as described, the ash was dissolved in dilute hydrochloric acid, and the CaO was estimated in this solution. The $P_2O_5$ was estimated in the filtrate and washings from the CaO estimation. The method used for the estimation of calcium was that developed by McCrudden (1911) for dealing with organic ashes, in which calcium, magnesium, iron, and phosphorus are present together. In the case of a small quantity of calcium such as we are dealing with here, the procedure is as follows:—The acid solution of the ash is diluted to 100 cc., made just alkaline with ammonia (a precipitate of calcium phosphate forms), then made just acid again with hydrochloric acid (the precipitate redissolves), and ten drops more of concentrated hydrochloric acid are added. Ten cc. of a 2·5% solution of oxalic acid are then added, and finally 8 cc. of a 20% solution of sodium acetate. The solution is either allowed to stand over night before filtering, or shaken vigorously in a stoppered vessel for ten minutes. The precipitate is then washed free from chloride in the usual way, and ignited to CaO, in which form it is weighed. In the present case the precipitates were ignited by placing them with the filters while still wet in the crucibles and introducing directly into a glowing muffle. The water in the crucible almost at once assumes the spheroidal condition, and the drying and ignition proceed quietly; there is no spluttering nor danger of breaking the porcelain crucible.

$P_2O_5$ was determined in the filtrate and washings from the above estimation. These were made just alkaline with

ammonia, and 2—4 cc. of magnesia mixture were added drop by drop, with constant stirring. After about half an hour one-third the volume of the solution of strong ammonia was added and the solution allowed to stand over night. The precipitate was washed free from chlorides with 1 : 3 ammonia in the usual way and ignited moist as described above, to $Mg_2P_2O_7$, in which form it was weighed. The ignited precipitates obtained in this way are often not white, but grey. The following estimations on a standard phosphate solution show, however, that the accuracy of the determination is not impaired by this. The standard solution of phosphate contained 3·3 gm. of microcosmic salt per litre and was standardised by evaporating a known volume to dryness, igniting, and weighing the sodium metaphosphate formed.

| Volume of Solution. | Weight of $NaPO_3$ | Weight of $Mg_2P_2O_7$ | Weight of $P_2O_5$ | Weight of $P_2O_5$ in 20 cc. |
|---|---|---|---|---|
| 40 cc. | 0·0349 gm. | ... | 0·0484 gm. | 0·02420 gm. |
| 40 „ | 0·0351 „ | ... | 0·0487 „ | 0·02435 „ |
| 30 „ | | 0·0574 gm. | 0·0366 „ | 0·02436 „ |
| 30 „ | | 0·0571 „ | 0·0364 „ | 0·02426 „ |
| 30 „ | | 0·0576 „ | 0·0367 „ | 0·02440 „ |

The amounts of $P_2O_5$ calculated from the weights of $Mg_2P_2O_7$ thus agree closely with those obtained from the weights of $NaPO_3$.

The following table gives the percentages of ash, CaO, and $P_2O_5$ found in a series of the deposits obtained by spinning milk in a centrifuge.

It will be seen that the deposits contain approximately equal weights of $P_2O_5$ and of CaO. The average of the ratio $P_2O_5/CaO$ is 1·01. The percentages of these substances found in the deposits vary from 3·2% to 4·7%. This variation is parallel to the variation in the ash content of the deposit, the ash itself having a fairly constant compo-

Table VI.

*Percentages of Ash, $P_2O_5$, and CaO in Deposits from Milk.*

| Milk. | Weight of Deposit. | Weight of Ash. | Percent of Ash. | Weight of $P_2O_5$ | Weight of CaO | Percent. of $P_2O_5$ | Percent. of CaO |
|---|---|---|---|---|---|---|---|
| 4 | 0·4457 | 0·0310 | 6·94 | 0·0142 | ... | 3·185 | ... |
| 6 | 1·4041 | 0·1001 | 7·13 | 0·0423 | 0·0444 | 3·01 | 3·16 |
| 9 | 0·6275 | 0·0618 | 9·85 | 0·0286 | 0·0294 | 4·56 | 4·68 |
| 10 | 0·5305 | 0·0431 | 8·12 | 0·0192 | 0·0194 | 3·61 | 3·68 |
| 12 | 1·5251 | 0·1157 | 7·59 | 0·0549 | ... | 3·34 | ... |
| 13 | 1·0551 | 0·0913 | 8·65 | 0·0391 | ... | 3·70 | ... |
| 15 | 0·5594 | 0·0452 | 8·09 | 0·0202 | ... | 3·61 | ... |
| 22 | 0·9015 | 0·0702 | 7·68 | 0·0288 | 0·0274 | 3·21 | 3·04 |
| 23 | 1·0162 | 0·0880 | 8·29 | 0·0383 | 0·0349 | 3·61 | 3·29 |

sition as is shown by the following figures giving the percentages of $P_2O_5$ and CaO calculated on the weight of ash instead of on the weight of the whole deposit.

Table VII.

*Percentages of $P_2O_5$ and CaO in Ashes of Deposits*

| Milk. | Percent. $P_2O_5$ | Percent. CaO | $P_2O_5$/CaO |
|---|---|---|---|
| 4 | 45·8 | ... | ... |
| 6 | 42·3 | 4·44 | 0·952 |
| 9 | 46·3 | 4·76 | 0·952 |
| 10 | 44·6 | 4·50 | 0·991 |
| 12 | 44·0 | ... | ... |
| 13 | 42·8 | ... | ... |
| 15 | 44·7 | ... | ... |
| 22 | 41·1 | 39·0 | 1·05 |
| 23 | 43·5 | 39·7 | 1·10 |

The average percentage of $P_2O_5$ in the ash of the deposit is thus 43·9 and the average percentage of CaO is 43·1.

As the above figures for CaO and $P_2O_5$ were obtained from the ash of the deposit, there is a possibility that the values for $P_2O_5$ may be low owing to the tendency of the phosphorus of organic compounds to volatilise during ignition. A comparison of the two following estimations shows, however, that the loss of phosphorus in the present case is small. The first of these results was obtained on

the substance ashed in the muffle in the usual way; the second result was obtained after destroying the organic matter with concentrated nitric and sulphuric acids (Neumann's (1902) acid-ashing process.)

*Deposit from Milk 51.*

| | Weight of Deposit. | Wt. of $Mg_2P_2O_7$ | Percent. of $P_2O_5$ |
|---|---|---|---|
| Dry ash ... | 0·2527 gm. | 0·0146 gm. | 3·68 |
| Acid "ash" ... | 0·1970 „ | 0·0121 „ | 3·91 |

These figures show a loss of phosphorus of about 6% during the ignition. This value is not much greater than the experimental error on the estimation of such small quantities of phosphorus as had to be dealt with in these cases.

### 5. Amount of Nitrogenous and Non-nitrogenous Organic Matter in the Deposit.

The ash-content of the deposit obtained from milk by spinning it in a centrifuge shows that there is present about 92% of material which disappears on ignition. The amounts of nitrogen in a series of these deposits have been determined by the method of Kjeldahl. The following are the results obtained:—

Table VIII.

*Nitrogen-content of Deposit.*

| Deposit. | Percentage of Nitrogen. |
|---|---|
| 17 | 11·9 |
| 25 | 10·7 |
| 35 | 10·95 |
| 36 | 11·95 |
| 37 | 12·05 |

The average percentage of nitrogen in these deposits is therefore 11·5. This corresponds to a percentage of protein of 72·8 (taking the nitrogen-content of the protein as 15·8%). On being allowed to stand for a day or two in the moist state these deposits set to a firm clot and developed a "cheesy" smell. A flocculent precipitate was formed

when a little acetic acid was added to a suspension of the deposit in water. These facts indicate the presence of caseinogen or its compounds. Two direct estimations of caseinogen were carried out as follows:—The deposits were suspended in volumes of water equal to the volumes of milk from which they were obtained, and the caseinogen was precipitated by the addition of one drop of 33% acetic acid to each 10 cc. of the suspension. The precipitates obtained were separated from the superfluid in the centrifuge, and washed three times with a solution of acetic acid (1 drop of 33% acetic acid to 10 cc. of water). The precipitates were then collected on tared filters dried to constant weight in a glycerine oven at 103°, and weighed. The following are the results obtained:—

*Percentage of Caseinogen in Deposit.*

| Deposit. | Weight of Deposit. | Weight of Caseinogen. | Percentage of Caseinogen. |
|---|---|---|---|
| 46 | 0·0779 gm. | 0·0441 gm. | 56·6 |
| 48 | 0·0916 ,, | 0·0531 ,, | 57·9 |

The greater part of the nitrogenous material of the deposit therefore consists of caseinogen. The precipitates of caseinogen were found to contain 2% of ash.

On subtracting the mean of these two percentages from the total percentage of protein in the deposit, as calculated from the total nitrogen-content it is seen that there is present in the deposit about 16% of protein not caseinogen. This nitrogenous matter is possibly derived from the general cellular débris from the epithelia of the different parts of the mammary gland of the cow. Such material is always obtained in the deposit formed when milk is allowed to stand, even in the milk from perfectly healthy cows (Ernst, 1913). A microscopic examination of the deposits obtained from milk in the present case showed

that the portions coming down first were very rich in cellular material, consisting for the greater part of cells resembling leucocytes but derived from the epithelium of the mammary gland (Hewlett, Villar and Revis, 1909; Ernst, 1913).

Subtraction of the total protein of the deposit from the total organic material shows the presence of 19% of non-nitrogenous organic matter. The clear superfluid from the caseinogen precipitation showed a powerful reducing action towards Fehling's solution, indicating the presence of a reducing body (lactose?). The percentage of lactose in the deposit was estimated by Pavy's method, caseinogen being first removed by precipitation with acetic acid, and the solution being boiled. In this way 16% of lactose was found to be present in the deposit. The Pavy's solution was standardised against a standard solution of Merck's lactose ($C_{12}H_{22}O_{11} + H_2O$) of approximately the same reducing power as the solution of the deposit.

Fat was tested for by allowing the deposit to stand under petroleum spirit for twenty-four hours, then pouring off the petroleum spirit and evaporating to dryness in a weighed vessel. No residue was left after volatilisation of the spirit. Fat is therefore apparently not present in the deposit in weighable amount. The microscopic examination of the deposit showed the presence of a certain number of granules which stained with osmic acid and Sudan III.

### 6. Solubility of the Deposit in Water.

When the deposit obtained from milk by spinning it in a centrifuge is shaken up in a volume of water equal to that of the milk from which it was removed, a considerable portion of it goes into solution. The following table gives the amounts of the total deposit and of the potential ash which may be dissolved in this way.

Table IX.

*Solubility of Deposit and of Potential Ash in Water.*

| Milk. | Total Deposit. | Total Ash. | Soluble Deposit. | Ash of Sol. Dep. | Percent. of soluble Deposit | Pot. Ash |
|---|---|---|---|---|---|---|
| 29 | 0·3443 gm. | 0·0297 gm. | 0·1019 gm. | 0·0268 gm. | 34·7 | 90·3 |
| 36 | 0·2070 „ | 0·0180 „ | 0·0985 „ | 0·0095 „ | 47·5 | 52·8 |
| 37 | 0·1084 „ | 0·0107 „ | 0·0697 „ | 0·0087 „ | 64·2 | 88·8 |
| 38 | 0·1286 „ | 0·0122 „ | 0·0318 „ | 0·0087 „ | 24·7 | 71·3 |
| 39 | 0·1339 „ | 0·0120 „ | 0·0936 „ | 0·0111 „ | 69·9 | 92·4 |

By the term "potential ash" is meant that portion of the deposit which after ignition forms the actual ash. The term is used to avoid speaking of the inorganic matter of the deposit, as it is uncertain what portion of the substances which go to form the ash is originally in an organic form of combination; part of the phosphorus and calcium for example, is probably present in the deposit in an organic compound (calcium caseinogenate).

The amount of the total deposit which goes into solution is seen to be very variable, ranging from 24·7 to 69·9%. The fraction of the potential ash which dissolves is greater still and varies from 52·8 to 92·4%. The solubility of the potential ash of the deposit is in marked contrast to that of the actual ash.

In the case of milk 29 the following figures were obtained:

| Total Ash. | Soluble Potential Ash. | Soluble Actual Ash. |
|---|---|---|
| 0·0297 | 0·0268 (90·3%) | 0·0055 (18·5%) |

The nature of the combinations of the elements which go to form the ash is therefore completely changed by ignition. The fact that part of this deposit from milk is soluble in water is interesting as it shows that in addition to the presence in milk of substances or conditions which keep insoluble materials in a state of fine suspension and prevent their precipitation, there are also present substances or conditions which keep soluble matter in a similar state.

**Summary.**

1. The removal of suspended matter from milk by spinning in a centrifuge does not lower the freezing point of the milk.

2. The rate of deposition of the suspended matter of milk in a centrifuge is not constant, first decreasing, then increasing.

3. The amount of ash in the deposit shows a variation in the opposite direction to that of the rate of deposition, first increasing then decreasing; the average ash-content of the deposit is 8%.

4. The pecentages of calcium and of phosphorus in the ash of the deposit are not subject to much variation; the average values are, CaO 43·1%, $P_2O_5$ 43·9%.

5. The nitrogen content of the deposit is also fairly constant; its average value is 11·5% (corresponding to 73% of protein).

6. The deposit contains about 57% of caseinogen.

7. No fat is present in the deposit.

8. The deposit contains about 19% of non-nitrogenous organic matter (16% lactose ?).

9. The average composition of the deposit is thus: ash, 8%; caseinogen, 57%; other protein, 16%; lactose, 16%; other non-nitrogenous organic matter, 3%.

10. A considerable portion (25–70%) of the deposit is soluble in water. The soluble portion contains the bulk (up to 90%) of the ash of the deposit.

In conclusion I wish to express my indebtedness to Professor Sir T. Anderson Stuart, in whose laboratory this work was done, and to thank Assistant-Professor Chapman for his advice and encouragement during the course of the work.

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# ON THE DIFFUSIBLE PHOSPHORUS OF COW'S MILK.

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[*Read before the Royal Society of N. S. Wales, August 5, 1914.*]

NUMEROUS data are available concerning the total quantities of the various elements which are present in milk. With regard to the forms of chemical combination and to the physical states in which these elements exist, however, our knowledge is much less complete. We know that milk contains substances both in solution and in suspension, but as to how the different elements are distributed between these states very few reliable data are to be found.

The separation of the substances in suspension in milk from those in solution has been attempted in three chief ways:—

1. By forcing milk through a filter made of some material having extremely fine pores, such as unglazed porcelain. A perfectly clear filtrate is obtained by this process.

2. By spinning milk in a centrifuge. In this way portion of the suspended matter of milk is obtained as a deposit.

3. By allowing the soluble portion of milk to dialyse away from the substances in suspension.

Although the first method of separation has been known for many years, few statements as to proportions of the substances in milk which pass through a porcelain filter are to be found, and there are considerable discrepancies

between the corresponding figures given by different authors. Further, it has been objected that the passage of milk through porcelain may not simply effect a mechanical separation of the suspended from the dissolved matter of milk, but changes may be induced which bring about the precipitation of substances originally in solution (see Raudnitz, 1902).

With regard to the method of separating the suspended matter from milk by spinning in a centrifuge, still less is known. Indeed, although it has been observed that a separation of some of the suspended matter of milk can be effected in this way, and one or two analyses of separator slime have been made (Fleischmann, 1901; Alson, 1908; Barthel, 1910), the only systematic attempt to determine the nature of the deposit obtained appears to be that of the present author (1914, 2). The investigations in this direction, however, have so far not thrown much light on the state of combination of the substances in solution and in suspension in milk beyond showing that calcium phosphate does not exist in suspension in milk as is generally believed, or rather that it is not deposited when milk is spun in a centrifuge. More complete information will be obtainable in this way only when a more perfect separation of the suspended matter has been brought about.

With regard to the separation of the suspended from the dissolved matter by means of dialysis, again very few data are available. When a body such as milk, in which there must exist a complex series of equilibria between dissolved and suspended substances, is allowed to dialyse against water, the effect is that of diluting the soluble constituents, which will dialyse out into the water. This dilution will disturb the equilibrium between dissolved and suspended matter, and may result in substances, originally in suspension, going into solution, just as a precipitate of an

"insoluble" salt may be dissolved up if the concentrations of the ions with which it is in equilibrium be diminished. Hence, when a quantity of milk is dialysed against a large volume of water the substances obtained in the dialysate will include not only those substances which exist in a state of true solution or in a dialysable or diffusible condition in the unchanged milk, but also those substances in suspension which can be made to go into solution by diluting with water. How considerable the amount of these substances may be has already been shown by the present author *(loc. cit.)*. The amounts of the substances in milk which are dialysable under these conditions therefore give no idea as to the amounts of dialysable or diffusible substances in the unchanged milk, the substance secreted by the mammary gland.

In this paper, those portions of the substances present in milk which can be made to dialyse into a large (unlimited) volume of water will be distinguished as the *dialysable* substances. Those substances which exist in unchanged milk in a dialysable or diffusible condition will be called the *diffusible* substances.

To determine the amount of the diffusible substances of milk some means are required by which these may first be separated without disturbing the equilibria existing between them and the remaining constituents; the process of dialysis as ordinarily carried out gives no help. A distinct advance in the study of diffusible substances was made by Moore and Bigland (1911) when they employed the method of dialysis against known volumes of water. In this way the equilibria were displaced to a definite, although still unknown, extent. Another improvement in the study of diffusible substances was that introduced by Zuntz and Loewy (1894), and later employed by Rona and Michaelis (1909). In this method, which is known as the method of

*compensatory dialysis*, the solution in which the amount of a certain constituent in a diffusible condition is to be determined is dialysed, not against water, but against a second solution so made up as to contain in a diffusible condition all the constituents of the second solution except the one the amount of which is to be determined in such concentrations that only the constituent under observation will diffuse, all the other constituents being balanced or compensated by equal concentrations outside the membrane through which dialysis takes place. Apart from the fact that one would require to know a great deal about the solution being examined before such an outer liquid for the dialyser could be prepared, this balancing of all of the constituents of a solution but one does not at all mean that the natural equilibria will remain undisturbed. Returning to the analogy with the equilibrium between a salt and its ions, it is known that any alteration in the concentration of any one of the ions will bring about a re-adjustment of concentrations of the other substances present necessary to reach a state of equilibrium under the changed conditions. Thus, although in special cases it may be possible to prepare these compensating solutions, as Rona and Michaelis have shown, this method does not seem to possess a wide range of applicability.

These authors, however, have employed another method for the examination of the diffusible substances of milk which reduces to a minimum all displacement of equilibria. This method is simply an extension of that of Moore and Bigland. The liquid under examination is allowed to dialyse against a known volume of water, but in this case the volume of the water is made very small in comparison with that of the milk (25 cc. of water to 1000 cc. of milk). The milk is thus only slightly diluted and a much truer estimate of the diffusible substances may be formed. By this method, and by the method of compensatory dialysis, Rona and

Michaelis have determined the amount of diffusible calcium in milk.

This paper is an account of the application of the method of quantitative dialysis to the study of the diffusible phosphorus of cow's milk. A few determinations of the diffusible calcium have also been made.

### The Milk Used.

The milk used for the first experiment was ordinary mixed milk as supplied by a city milk-vendor. This milk is about twelve hours old before it reaches the consumer, and is generally pasteurised. Such milk was found quite unsuitable for the present work as even the addition of toluol did not prevent its souring before the completion of the dialysis. The remaining experiments were made upon the milks of single cows. Each cow from which a sample of milk was taken, was milked directly into a vessel containing 10 cc. of toluol for each litre of milk collected. The access of bacteria is very much hindered in this way; milk collected as described keeps sweet for several days. The essential point here seems to be to prevent the entrance of bacteria, as it has been shown that although toluol kills organisms, such as yeasts, it has practically no effect on the rate of action of the enzymes produced by them (Harden, 1910). Toluol was chosen as the disinfectant as being a hydrocarbon and practically insoluble in water it did not seem likely to have any marked effect on the substances in an aqueous solution such as milk. Toluol does exert a solvent action on the fat of milk, however.

The samples of milk were all collected at about 12 noon; the last milking of the same cow had occurred in each case at about 4 a.m. of the same day. The milk obtained was generally the first portion of the milking.

### The Dialyses.

The dialysis of milk against water was allowed to take place through celloidin membranes. These membranes

were prepared in the form of sacs by covering the inside of a test-tube with a layer of a solution of celloidin and allowing the solvent (alcohol-ether) to evaporate off. Before the ether and alcohol have completely disappeared from the layer of celloidin deposited in this way in the test-tube, the latter should be filled with water and the remainder of the alcohol and ether dissolved out. Membranes prepared by allowing all the ether and alcohol to evaporate off in the air are very brittle. The sacs formed in this way do not adhere firmly to the inside of the test-tube, and with a little patience can easily be coaxed away from the glass. These celloidin membranes, when prepared in the right way are transparent and flexible. They withstand a considerable tensile stress but are very easily torn. If water be poured into the test-tube before enough of the solvent has evaporated from the celloidin, the membrane formed will be opalescent and will tear so easily as to be useless. A suitable solution for the preparation of these membranes consists of equal parts of ether and absolute alcohol containing 5% of celloidin (see Abel, Rowntree and Turner, 1914).

The dialysates obtained in these celloidin sacs are perfectly clear when bacterial contamination is avoided. When a sac has once been used, however, it is rather difficult to clean properly inside, and the dialysate becomes infected and turbid in spite of the presence of toluol in the surrounding milk. In the later experiments this source of contamination was avoided by using a new diffusion sac for each dialysis.

In carrying out the dialyses 25 cc. of water were put in the celloidin sac and the latter suspended in one litre of milk. It was found that no further change occurred in the concentrations of the substances which had diffused through into the water after the dialysis had continued for twenty

four hours. At the end of this time the molecular concentrations of the dissolved substances on each side of the celloidin membrane were practically the same. The relative molecular concentrations of milk and its dialysates were determined by measuring the depressions of the freezing point of water (△) due to the substances in solution in these liquids. The following are the figures obtained.

*Values of Δ for spun milk, twenty-four hour dialysate, and forty-eight hour dialysate.*

| Experiment. | Spun milk. | 24-hr. Dialysate. | 48-hr. Dialysate. |
|---|---|---|---|
| 61 | 0·564° | 0·580° | 0·576° |
| 62 | 0·576 | 0·547 | 0·533 |
| 63 | 0·569 | 0·530 | 0·526 |
| 64 | 0·560 | 0·535 | 0·539 |

These results show that the values of △ for milk from which the fat has been removed by spinning in a centrifuge (spun milk) and for the twenty-four hour and forty-eight hour dialysates agree to within about 5%, and that the freezing point of the dialysate does not alter its value once it has approximated to that of milk. When it is remembered that the diffusible part of the milk has been diluted to the extent of 2·5% it will be seen that a closer agreement between the freezing points of milk and its dialysates is hardly to be expected. An experiment in which the values of △ for spun milk, dialysate and the milk in equilibrium with the dialysate were determined, gave the following results.

| Spun Milk. | Dialysate. | Outer Liquid. |
|---|---|---|
| 0·560° | 0·542° | 0·548° |

The values of △ for the dialysate and the liquid in equilibrium with it thus agree very closely.

It will be noticed that the freezing points of the dialysates have been compared, not with the milk with which

they were in equilibrium, but with the same milk freed from fat in the centrifuge. This was done because the freezing point of spun milk is more easily determined than that of the same milk still containing fat. It has already been shown (*loc. cit.*) that the freezing points of whole and spun milk are practically the same.

The milk on which all the work described in the present paper was done contained 1% of toluol as already stated. It was thought that the presence of the toluol might have some effect on the freezing point of the milk, but the following determinations of the value of $\triangle$ for spun milk (*a*) without toluol, (*b*) containing 5% of toluol, show that this is apparently not the case.

| Spun Milk Alone. | Spun Milk + Toluol. |
|---|---|
| 0·552° | 0·556° |

The effect of the toluol, if any, is thus small.

All these determinations of freezing point were carried out in the manner previously described (*loc. cit.*). The agreement between the freezing points of the corresponding liquids is within the limit of accuracy of the method there set down. Each value of $\triangle$ given is the mean of at least three determinations having an extreme difference of not more than about 0·005°.

During the course of a dialysis the volume of liquid put into the celloidin sac does not remain constant, but diminishes, as the following results show.

*Volume of liquid in celloidin sac before and after completion of dialysis.*

| Experiment. | Original volume. | Volume of dialysate. |
|---|---|---|
| 55 | 25 cc. | 18·6 cc. |
| 56 | 25 ,, | 15·5 ,, |
| 58 | 25 ,, | 16·2 ,, |

These figures were obtained for the dialysis of spun milk; they show the osmotic effect which occurs before the con-

centrations of the substances in solution have become the same on each side of the membrane.

## Results.

Having demonstrated that the process of dialysis as carried out in the present investigation leads to a definite state of equilibrium between the substances on each side of the membrane of the dialyser, we may now enquire what concentrations of substances in the dialysate are in equilibrium with those in the milk. In this paper I shall deal only with the concentrations of calcium and phosphorus. The amounts of calcium (expressed as CaO) were determined in addition to the amounts of phosphorus (expressed as $P_2O_5$) only in the first few experiments. $P_2O_5$ alone was determined in the later experiments as the length of time required for the analyses was so much increased when CaO was estimated as well, and as the amount of diffusible CaO in milk has already been determined by Rona and Michaelis (*loc. cit.*) by this method.

For these estimations as a rule not more than 10 cc. of dialysate were available; in the case of milk, portions of 20 cc. of spun milk were used, as the removal of the fat considerably reduces the amount of organic matter which has to be destroyed before proceeding to the actual estimation. The organic matter in the liquids under examination was destroyed, and the calcium and phosphorus oxidised by the acid-ashing process of Neumann (1902) as modified by Plimmer and Bayliss (1906), *i.e.*, by oxidation with a mixture of concentrated nitric and sulphuric acids.

*Use of spun milk.*—It has already been shown that the removal of the fat of milk by mechanical means does not alter the freezing point (Wardlaw, *loc. cit.*), that is, removes nothing from solution in the milk. This is no justification for concluding however, that the percentage of any particular constituent such as CaO or $P_2O_5$ is the same in spun

milk as in whole milk. We must therefore ascertain how the contents of phosphorus and calcium differ, if at all from those of whole milk before we can with strict justification deduce from a comparison of the amounts of these constituents in spun milk and in the dialysate of whole milk the proportions of them which exist in a diffusible condition in whole milk.

When milk is spun long enough in a centrifuge (for over half an hour), the fat collects in a solid layer which may be easily removed from the top of the liquid. The liquid portion is therefore diminished by a volume equal to that of the fat or cream. The following measurements allow this diminution of volume to be calculated in percentages of the original volume of the milk. The milk was spun in cylindrical, flat-bottomed tubes; the volumes of the different portions of the milk were therefore proportional to the lengths of tube occupied by them.

*Diminution of volume of the liquid part of milk due to the removal of the fat or cream in a centrifuge.*

| Milk. | Total height in tube. | Length of liquid. | Length of fat. | Diminution of volume. |
|---|---|---|---|---|
| 3 | 13·0 cm. | 12·3 cm. | 0·7 cm. | 5·4 % |
| 4 | 12·7 „ | 12·0 „ | 0·7 „ | 5·5 , |
| 6 | 13·3 „ | 12·6 „ | 0·7 „ | 5·3 „ |
| mean | ... | ... | ... | 5·4 „ |

It will thus be seen that if the fat or cream removed contain no CaO or $P_2O_5$ the amounts of these in a given volume of milk will be increased to the extent of 5·4% by merely spinning in a centrifuge. As, however, cream contains a certain amount of ash, a direct determination of the ash, CaO and $P_2O_5$ in the fat or cream removed from 100 cc. of milk was made. The following results were obtained.

*Amounts of ash, CaO and $P_2O_5$ in the fat or cream of* 100 *cc. of milk.*

| Ash. | CaO. | $P_2O_5$. |
|---|---|---|
| 0·0180 gm. | 0·0063 | 0·0046 |

These quantities amount to 2·4% of the corresponding constituents of whole milk.

The total result of the removal of the fat from milk in this way is thus a "concentration" of the remaining constituents to the extent of 5·4% (the actual molar concentration of the substances in solution is not changed, v. s.), and the removal of 2·4% of the substances which go to form the ash. On the whole there is therefore a "gain" of these substances in a given volume of liquid equal to 3·0% (5·4 − 2·4).

Direct determinations of the amounts of $P_2O_5$ in whole and spun milk were also made. These gave the following results:—

*Percentage increase of $P_2O_5$ in milk due to the separation of the fat in a centrifuge.*

| Milk. | $P_2O_5$ in 100 cc. of | | Percentage increase. |
|---|---|---|---|
| | Whole Milk. | Spun Milk. | |
| 3 | 0·210 gm. | 0·217 gm. | 3·5 |
| 4 | 0·216 „ | 0·222 „ | 3·0 |

These direct measurements thus lead to the same result as was deduced above. The accuracy with which phosphorus could be estimated was not high enough to allow of complete reliance being placed on results obtained by the direct method alone.

We may now proceed to compare the amounts of CaO and $P_2O_5$ in spun milk with those in the dialysates of whole milk, remembering that the values obtained for the first quantities must be diminished by 3·0% if strictly corres-

ponding figures are required. The correction is not large, and for comparative purposes need not be made.

*Amount of diffusible CaO.*—The estimations of CaO were made by the method of Aron (1907) in which the Ca is precipitated from the acid ash as $CaSO_4$ by the addition of alcohol. The figures below give the proportions of diffusible CaO found in three samples of milk.

*Percentage of CaO of milk in a diffusible condition.*

| Milk. | CaO in 100 cc. of | | | | Percentage in dialysate. | |
|---|---|---|---|---|---|---|
| | Spun milk. | | Dialysate. | | | |
| | A | B | 24-hour. | 48-hour. | 24-hour. | 48-hour. |
| 55 | 0·180 | 0·166 | 0·061 | ... | 35·3 | ... |
| 56 | 0·164 | 0·153 | 0·061 | ... | 38·3 | ... |
| 58 | 0·280 | ... | 0·086 | 0·077 | 30·8 | 27·4 |

The agreement between the duplicate analyses is not good, but the results show that roundly 30–40% of the calcium of milk is present in a diffusible state. These figures are rather lower than those given by Rona and Michaelis for the four samples of milk examined by them. Their figures range from 40 to 50%; they give no duplicate analyses.

*Amount of diffusible $P_2O_5$.*—The phosphates in the acid ash were precipitated in the way described by Neumann. These precipitates were dissolved in dilute ammonium hydroxide, the $P_2O_5$ was precipitated again as $MgNH_4PO_4$, and finally weighed as $Mg_2P_2O_7$ in the usual manner. The details of these processes will be found in the author's previous papers (*loc. cit.* 1 and 2). The accompanying figures show the results obtained for the amounts of diffusible $P_2O_5$.

*Percentage of $P_2O_5$ of milk in a diffusible condition.*

| Milk. | $P_2O_5$ in 100 cc. of Spun milk. | | Dialysate. | | Percentage in dialysate. | |
|---|---|---|---|---|---|---|
| | A | B | 24-hour. | 48-hour. | 24-hour. | 48-hour. |
| 55 | 0·235 | 0·232 | 0·153 | ... | 35·0 | ... |
| 59 | 0·216 | 0·212 | 0·076 | 0·136 | 35·5 | ... |
| 60 | 0·233 | 0·235 | 0·106 | 0·131 | 45·3 | ... |
| 61 | 0·259 | 0·250 | 0·138 | 0·139 | 54·1 | 54·5 |
| 62 | 0·263 | 0·261 | 0·112 | 0·110 | 42·1 | 42·0 |
| 63 | 0·220 | 0·225 | 0·123 | 0·122 | 55·3 | 54·8 |
| 64 | 0·221 | 0·217 | 0·106 | ... | 48·6 | ... |

These results show that the amount of diffusible $P_2O_5$ of cow's milk varies from 35 to 55%.

The amount of the soluble or diffusible calcium and phosphorus in milk is thus by no means consistent, but varies between rather wide limits. This variation is striking when the comparative constancy of the freezing point, and therefore of the total amount of dissolved matter is remembered. Jackson and Rothera (1914) have examined this peculiarity and have shown that there is a reciprocal relation between the salts in solution in milk and the amount of milk sugar.

**Summary.**

1. When a large volume of milk is dialysed against a small volume of water, the freezing point of the dialysate after twenty-four hours approximates to that of the milk, and does not change as the dialysis is continued; a definite state of equilibrium is therefore reached.

2. Milk freed from fat in a centrifuge contains 3% more ash-forming substances than whole milk.

3. The diffusible calcium of cow's milk amounts to 30–40% of the total present.

4. The diffusible phosphorus of cow's milk amounts to 35–55% of the total present.

In conclusion I wish to express my indebtedness to Sir Thomas Anderson Stuart, in whose laboratory this work was done, and to thank Assistant-Professor Chapman for the advice and encouragement he has given me during the work.

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*Note.*—The milk used for the experiments described in the author's paper on the "Nature of the Deposit obtained from Milk by Spinning in a Centrifuge," p. 152, this volume) was mixed milk about twelve hours old, obtained from a city milk vendor.

that which the composition of any given sample of human milk is most likely to be. This fact is not very generally recognised, although a few investigators have pointed out the indefiniteness of these mean figures, and have despaired of making any general quantitative statement as to the composition of human milk (Hammarsten, Völtz). Other workers, for example Leeds, have endeavoured to give additional value to the mean of the results of their analyses by stating also the highest and lowest figures obtained for the amount of each constituent, and thus indicating the limits between which the variations occurred.

In the following table are given typical sets of figures representing the means of the results obtained for the percentages of the various constituents in series of analyses of human milk. The maximum and minimum values for the amount of each constituent are also given. The examples chosen are from the only three exhaustive modern investigations of the composition of human milk which the present author has been able to find. The original figures of an extensive series of analyses carried out by Adriance and Adriance (1898) unfortunately could not be obtained.

Table I.—*Typical mean, maximum, and minimum figures for the density and composition of human milk*

| | Density. | Total Solids. | Fat. | Solids not fat. | Protein. | Milk Sugar. | Ash. |
|---|---|---|---|---|---|---|---|
| Maximum | 1·0353 | 16·8 | 6·9 | 12·1 | 4·9 | 7·9 | 0·37 |
| Mean | 1·0313 | 13·3 | 4·1 | 9·1 | 2·0 | 6·9 | 0·20 |
| Minimum | 1·0260 | 10 9 | 2·11 | 6·6 | 0·85 | 5·4 | 0·13 |
| Maximum | 1·0426 | 17·1 | 8·8 | ... | 4·05 | 8·9 | 0·50 |
| Mean | 1·0313 | 12·0 | 3·07 | 8·2 | 1·97 | 6·6 | 0·26 |
| Minimum | 1·0240 | 8·6 | 0·47 | ... | 1·02 | 4·4 | 0·17 |
| Maximum | ... | 13·9 | 5·8 | ... | 2·04 | 7·5 | 0·34 |
| Mean | ... | 12·0 | 3·36 | 8·6 | 1·35 | 6·4 | 0·23 |
| Minimum | ... | 9·4 | 1·27 | ... | 0·81 | 5·35 | 0·11 |

The first set of figures is from sixty analyses of the milk of women living in America, carried out by Leeds (1884); the second set of figures is from ninety-four analyses of the milk of women living in England, carried out by Carter and Droop Richmond (1898); the third set of figures is from fifty-three analyses of the milk of women living in Germany, due to Camerer and Söldner (1895, 1896, 1898).

From this table will be seen the amounts to which the percentages of the various constituents of human milk may vary. It will be noticed that these variations are greatest in the case of the fat, and least in the case of the sugar. It will be seen also that the average figure given for the protein-content of human milk by Camerer and Söldner, is considerably lower than that given by the other investigators. The former workers estimated protein by determining the nitrogen of the tannic acid precipitate from the milk and multiplying this quantity by the factor 6·25, the latter workers estimated the protein by the method of Ritthausen (precipitation by means of alkaline copper sulphate, extraction of the precipitate with ether, and direct weighing, or estimation of the nitrogen in it).

Practically all of the analyses of human milk available to the present author were, with the exception of the results of Leeds and of Adriance and Adriance, who analysed the milk of women living in America, of the milk of women living in Europe. In the present communication the results of the analyses of samples of milk from over one hundred European women living in Australia are submitted. A simple application of the theory of probability to these results has been made in the endeavour to arrive at a better defined general quantitative statement as to the composition of the milk examined than is given by the admittedly inadequate method of simply stating the mean, maximum, and minimum values for each constituent. The influence of the

age and of the number of pregnancies of the mother, and of the time of lactation, on the composition of the milk has been studied. The effect of the length of the period of rest which has elapsed since the last withdrawal of milk from the breast and of the volume of the sample, and the difference between the average compositions of the milk from each breast, have also been examined.

The most striking feature of the results obtained is that they seem to give further support to the view that the secretion of the fat of human milk occurs independently of that of the other constituents, since the percentages of the latter show marked tendencies to approach certain "most probable" values, the percentages of fat show not such tendency, but the occurrence of any one percentage within wide limits seems to be no more probable than that of any other.

**2. The samples of human milk and methods of analysis.**

The samples of human milk of which the analyses are given in this paper were obtained from patients of the Royal Alexandra Hospital for Women, Sydney, through the courtesy of Miss E. M. Buckley, M.B., Pathologist to the Hospital, to whom I express my best thanks.

The patients who come to this hospital for confinement remain there in the ordinary course of events for ten or eleven days after the birth of the child, and of the 105 samples of human milk of which the analyses are given only one represents the milk secreted after a period longer than this after child-birth. The great majority of the samples were obtained four or five days after the birth of the child.

The nurses who obtained the milk were at first instructed to obtain it by massaging the breast of the patient, as a better sample is said to be obtained in this way than with a pump (Engel), but as the nurses seemed to have great

difficulty in collecting samples large enough for analysis by this means, the use of the breast pump was resorted to, and all of the samples except the first two or three were collected with it.

In the case of each sample of human milk the nurses were instructed to record the following particulars:—

1. Age of mother.
2. Number of pregnancies.
3. Age of child.
4. Time of collection of sample.
5. Time of last suckling.
6. Breast from which sample was taken.

The nurses were directed to obtain the whole sample from one breast whenever possible, and to endeavour to empty the breast completely. The samples of milk were collected between 6 a.m. and 9 a.m.; the analyses were begun at about 10 a.m. of the same morning, so that all the estimations were made upon perfectly fresh milk.

*Methods of Analysis.*—Determinations of density, total solids, fat, and total protein, were made on the samples of human milk obtained. The amounts of solids not fat, and of solids not fat and not protein (chiefly milk-sugar) have been calculated by difference.

*The densities* of the milks were determined with a pyknometer. The pyknometer used for the first twenty-five samples had a volume of about 8·5 cc., but as the quantities of milk obtained were occasionally smaller than this, a pyknometer having a volume of only about 2·7 cc. was used for the rest of the determinations. The levels of the pyknometer were adjusted after it had hung in a water thermostat for at least ten minutes; the densities given are for a temperature of 25° C. Their values are given to one part in 10,000.

*The total solids* of the milk were determined on 1 cc. measured from a pipette and evaporated to dryness on a watch-glass in a glycerine oven at 103° C. This small quantity of milk can be spread out in a thin layer on the watch-glass and dries fairly quickly at 103° C. In the calculation of the percentage of total solids the volume of the milk is multiplied by its density to give the weight. The values of the percentage of total solids are given to one part in one hundred.

*The fat* in the samples of milk was determined by the Röse-Gottlieb (1888, 1891) method. In this method the fat is extracted from the milk mixed with alcohol and ammonium hydroxide by means of a mixture of ether and petroleum spirit of low boiling point, the fat dissolved in this mixture being weighed after evaporating off the spirit. The results of the analyses are given to one part in one hundred.

It has been stated by Radenhausen (1881), Forster (1881), Mendes de Leon (1881), and by others, that the percentage of fat in human milk is lower in the portions first withdrawn than in the portions withdrawn later, and Reyher (1905), Forest (1906), and Engel (1906) have suggested that on account of this fact the whole of the milk contained in the mammary gland should be taken for analysis in order to determine the average percentage of fat in it, or, failing this, that equal portions should be taken for analysis at the beginning and the end of the withdrawal of the sample, the mean of the percentages of fat found in these two portions being taken as the average percentage of fat in the total amount of milk withdrawn. Helbich (1912), who reinvestigated this question later, did not find this dependence of the percentage of fat in human milk on the volume withdrawn from the breast, however. He therefore states that the inverse relation between volume and percentage of fat which Engel claims to have observed, does not exist.

In the present work an endeavour was made to comply with the above recommendations by having the mammary gland emptied as completely as possible for each sample.

It has also been shown by Engel (1910), that the percentage of fat in human milk is lower the longer the interval of time is which has elapsed since milk was last withdrawn from the gland. Account has been taken of this statement in the present case by noting the time which had elapsed for each sample since the last withdrawal of milk from the same gland, with a view to ascertaining whether any similar effect of time on the percentage of fat in the milk secreted was to be observed.

In the case of the cow, the fact that the last portions of a milking are richer in fat than the first is well known, and seems to have been first demonstrated by Parmentier and Deyeux as long ago as 1790. It is also well known to dairymen that the shorter the period of rest between two successive milkings of a cow the richer in fat is the milk yielded at the second milking, but the smaller is the volume obtained.

*The total protein* in the first fifty-three samples of human milk was estimated by the method of Sikes (1906). In this method, 5 cc. of milk to which two or three drops of a saturated solution of citric acid have been added to hinder the precipitation of salts, are mixed with 100 cc. of absolute alcohol, and boiled. The proteins are completely precipitated, and the fat, sugar, and extractives go into solution in the hot alcohol. The precipitate is spun in a centrifuge while hot and washed twice with 30 cc. of boiling alcohol. In the present case large quantities of absolute alcohol and a centrifuge in which the washing could be done conveniently were not available. The precipitation was therefore brought about by means of 95% methylated spirit, and the precipitate was washed twice with 50 cc. of the

spirit on a filter surrounded by a steam coil which kept the liquid hot. No protein could be detected in the filtrate from this precipitation by means of Millon's reagent. This reagent as used in the present case was capable of detecting one part in 20,000 of protein in solution, a quantity which would amount to about 0·25% of the protein estimated. No sugar could be detected in the second washing by means of Fehling's solution. This reagent, as used in the present case was capable of detecting one part of lactose in 8,000, a quantity which would amount to about 0·2% of the whole of the lactose present. No simple qualitative test for fat of a well-defined order of delicacy was known, but a comparison of the results obtained by this method with those obtained by another method (described below) in which the fat was completely removed from the milk before the estimation of protein showed that the amount of any fat not removed by the washing was within the experimental error.

In samples 71 to 122 a modification of the above method was used for the estimation of protein. Instead of a fresh sample of milk being taken, an aliquot part of the aqueous layer of the liquids obtained in the estimation of fat by the Röse-Gottlieb method was used. The method thus modified has the advantage that the fat and protein are both estimated on the same sample of milk, and that the fat in the liquid in which the protein is estimated has already been completely removed. The quantity of milk required for analysis is in this way much reduced, a determination of both fat and protein being easily made on 5 cc. of milk. Further, it is unnecessary to take precautions to keep the liquids hot during filtration in order to keep fat in solution. The first precipitation must, however, still be made from boiling alcohol, or the precipitate will not come down completely, and hot alcohol is more convenient for the washings than cold. Citric acid was added before the precipitation

as in Sikes' method, but was found later not to reduce the ash-content of the precipitate of protein. The percentage of ash in the precipitates was found to be about five; Sikes found the percentage of protein to be about three in his precipitates, but in the present case the percentage of ash in the precipitates obtained by his method was the same as in those obtained by the method described.

The aqueous layer of the liquids obtained in the estimation of fat by the Röse-Gottlieb method is not clear, but opalescent, owing to the presence of substances in colloidal solution, the chief of which are caseinogen and phosphates. On standing, part of this fine suspension slowly rises and collects beneath the ethereal layer. When this has occurred, the distribution of the substances in the aqueous layer is no longer uniform, so that, in taking an aliquot part of this layer for the estimation of protein. a representative sample might not be obtained, and a fallacious result might be arrived at, although, as the precipitate is probably composed of phosphates which have been thrown down by the addition of ammonia, the effect of this uneven distribution of the contents of the aqueous layer upon the amount of protein found would probably be insignificant. The liquids, however, should not be allowed to stand longer than about one hour, or should be shaken up and allowed to settle again if they have stood too long.

The following protocol of an estimation of fat and protein on the same sample of milk will give a more definite idea of the method outlined above.

Ten cc. of human milk in a 100 cc. stoppered measuring cylinder were mixed with 2 cc. of 10% ammonium hydroxide and 10 cc. of 95% methylated spirit; 25 cc. portions of ether and of petroleum spirit were then added, the mixture being thoroughly shaken after each addition, and finally allowed to stand for about one hour. The levels of the ethereal and aqueous layers were then found to be at 70·6 cc and 19·0 cc., respectively. The volume of the

ethereal layer was therefore 51·6 cc., and that of the aqueous layer 19·0 cc. Twenty cc. of the ethereal layer were pipetted off and the spirit was driven off in a weighed vessel. The fat which remained behind weighed 0·1257 gm. The percentage of fat in the milk was therefore: 0·1257/10 × 51·6/20 × 100/1·030 or 3·14, the density of the milk being taken as 1·030. Ten cc. of the aqueous layer were now pipetted off and the protein in this liquid was precipitated as described above. The dried precipitate weighed 0·1146 gm. The percentage of protein in the milk was therefore; 0·1146/10 × 19·0/10·0 × 100/1·030 or 2·11.

The following series of estimations of the amount of protein in human milk show the degree of concordance which is attainable between individual estimations on the same sample by this method:

| Sample A. | Sample B. | Sample C. |
|---|---|---|
| 2·62% | 3·20% | 2·59% |
| 2·63 | 3·22 | 2·57 |
| 2·60 | 3·21 | 2·56 |
| 2·63 | | |
| 2·62 | | |

The results obtained by this method thus agree together to within about 1%.

In order to ascertain whether the results obtained by this method are strictly comparable with those obtained by the method of Sikes, six estimations of the amount of protein in a sample of milk were carried out by each method. The mean result of the six estimations by Sikes' method gave the percentage of protein as 1·36, while the mean of the six estimations by the present method gave the percentage as 1·35. The two methods therefore give closely agreeing results. The percentages of protein are given to one part in one hundred in the accompanying tables.

Of the remaining constituents of human milk, which have not been directly estimated, 90% are made up of milk sugar. The chief other substances present are: ash 0·2%; nitrogenous extractives, principally urea, 0·2%; citric acid

0·05%. The total quantity of these substances is small, so that comparatively large variations in their amount would not materially alter the total amount of these remaining constituents of human milk, and so a reliable estimate of the amount of sugar present may be arrived at by simply deducting 0·5 from the percentage of substances obtained by subtracting the percentages of fat and of protein from the percentage of total solids. In the table of results the percentages of these solids not fat and not protein are given, and from them the percentages of sugar may be calculated by making the above deduction.

The percentages of solids not fat have also been given in the table of results, as this portion of the milk has been observed to be more constant in amount than the other constituents, and importance has therefore been attached to it for purposes of comparison.

### 3. Results.

The results of the analyses made, and the particulars of the samples of milk used are given in the following table. The figures given in the several columns represent: (1) the number of the sample; (2) the breast from which the sample was taken, R = right breast, L = left breast, B = both breasts; (3) the age of the mother in years; (4) the number of the pregnancy; (5) the age of the child in days; (6) the time in hours since the last application of the child to the breast; (7) the volume of the sample in cc.; (8) the density of the sample; (9) the percentage of total solids; (10) the percentage of fat; (11) the percentage of solids not fat; (12) the percentage of protein; (13) the percentage of solids not fat and not protein. The results given in the table have been arranged in descending order of the number of pregnancies of the mother, the results for any given number of pregnancies being in descending order of the age of the mother and of the time since the child was last suckled.

Table II.—*Results of analyses of human milk and particulars of samples.*

| Number. | Breast. | Age of Mother. | Pregnancy. | Age of Child. | Hours since suckled. | Volume of sample. | Density. | Total solids. | Fat. | Solids not fat. | Protein. | Solids not fat nor protein. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42 | B | 14 | 1 | 5 | 1·0 | 19 | 1·0297 | 10·4 | 2·10 | 8·3 | 2·02 | 6·3 |
| 69 | R | 17 | 1 | 4 | 7·0 | 15 | 1·0360 | 12·3 | 2·78 | 9·5 | ... | ... |
| 98 | R | 17 | 1 | 9 | 1·0 | 8 | 1·0291 | 14·0 | 3·95 | 10·0 | 1·68 | 8·3 |
| 121 | B | 18 | 1 | 5 | 1·5 | 31 | 1·0333 | 13·0 | 3·28 | 9·7 | 2·26 | 7·5 |
| 67 | B | 18 | 1 | 10 | 0·5 | 14 | 1·0297 | 13·7 | 4·32 | 9·4 | ... | ... |
| 58 | R | 19 | 1 | 4 | 1·25 | 26 | 1·0325 | 13·6 | 4·38 | 9·2 | 1·81 | 7·4 |
| 101 | R | 19 | 1 | 4 | 1·75 | 16 | 1·0358 | 10·8 | 1·09 | 9·7 | 1·29 | 8·4 |
| 99 | L | 19 | 1 | 4 | 3·0 | 18 | 1·0327 | 10·7 | 1·42 | 9·3 | 1·67 | 7·6 |
| 72 | B | 19 | 1 | 9 | 1·5 | 24 | 1·0329 | 13·2 | 3·61 | 9·6 | 1·53 | 8·1 |
| 78 | B | 20 | 1 | 4 | 2·0 | 23 | 1·0301 | 14·8 | 2·55 | 12·2 | 1·23 | 11·0 |
| 32 | L | 20 | 1 | 5 | 2·5 | 20 – | .. | 11·9 | 2·39 | 9·5 | 1·87 | 7·6 |
| 60 | B | 20 | 1 | 5 | 3·25 | 13 | 1·0318 | 13·3 | 3·85 | 9·4 | 2·42 | 7·0 |
| 30 | R | 20 | 1 | 7 | 7·75 | 20 + | 1·0334 | 11·5 | 5·26 | 6·2 | 1·82 | 4·4 |
| 102 | L | 20 | 1 | 11 | 0·5 | 9 | 1·0320 | 12·2 | 5·88 | 6·3 | 2·50 | 3·8 |
| 23 | R | 20 | 1 | 5 | ... | 20+ | 1·0330 | 13·2 | 2·98 | 10·2 | 2·20 | 8·0 |
| 113 | L | 21 | 1 | 4 | 1·25 | 10 | 1·0372 | 11·7 | 1·42 | 10·3 | 3·00 | 7·3 |
| 117 | L | 21 | 1 | 4 | 3·0 | 9 | 1·0337 | 12·2 | 2·51 | 9·7 | 2·41 | 7·3 |
| 44 | R | 21 | 1 | 5 | 1·0 | 16 | 1·0338 | 12·0 | 2·71 | 9·3 | 2·60 | 6·7 |
| 89 | B | 22 | 1 | 3 | 2·0 | 20 + | 1·0330 | 12·8 | 3·14 | 9·7 | 2·32 | 8·5 |
| 24 | L | 22 | 1 | 3 | 7·75 | 20+ | 1·0311 | 13·3 | 3·87 | 9·4 | 2·08 | 7·3 |
| 96 | R | 22 | 1 | 4 | 3·5 | .. | 1·0331 | 12·9 | 3·31 | 9·6 | 1·82 | 7·8 |
| 108 | R | 22 | 1 | 7 | 1·5 | 20 | 1·0312 | 12·8 | 3·46 | 9·3 | 1·35 | 8·0 |
| 46 | B | 23 | 1 | 5 | 0·5 | 16 | 1·0298 | 12·9 | 3·44 | 9·5 | 2·18 | 7·3 |
| 82 | B | 23 | 1 | 5 | 11·0 | 27 | 1·0332 | 12·6 | 2·82 | 9·8 | 1·81 | 8·0 |
| 86 | B | 23 | 1 | 6 | 1·5 | 15 | 1·0331 | 12·5 | 3·40 | 9·1 | 1·73 | 7·4 |
| 95 | R | 23 | 1 | 10 | 1·0 | ... | 1·0337 | 12·7 | 2·52 | 10·2 | 1·65 | 8·4 |
| 64 | L | 24 | 1 | 6 | 0·5 | 35 | 1·0344 | 11·5 | 1·93 | 9·6 | 1·67 | 7·9 |
| 38 | B | 24 | 1 | 3 | 1·0 | 20 – | . . | 10·2 | 2·21 | 8·0 | 2·86 | 5·1 |
| 52 | R | 24 | 1 | 7 | 0·5 | 14 | ... | 10·7 | 2·08 | 8·7 | 2·88 | 5·8 |
| 55 | R | 24 | 1 | 18 | 2·0 | 8 | ... | 13·7 | 4·59 | 9·1 | ... | ... |
| 31 | R | 25 | 1 | 4 | 0·5 | 20+ | 1·0343 | 12·6 | 2·86 | 9·7 | 2·30 | 7·4 |
| 48 | B | 25 | 1 | 4 | 6·5 | 10 | .. | 9·5 | 0·56 | 8·9 | 2·43 | 6·5 |
| 28 | L | 25 | 1 | 8 | 2·75 | 20+ | 1·0308 | 11·3 | 2·37 | 7·9 | 2·45 | 6·3 |
| 104 | B | 26 | 1 | 3 | 1·0 | 9 | 1·0308 | 11·2 | 2·29 | 8·9 | 1·66 | 7·2 |
| 103 | L | 26 | 1 | 6 | 1·0 | 15 | 1·0302 | 12·2 | 2·78 | 9·4 | 1·77 | 7·6 |
| 57 | L | 26 | 1 | 11 | 1·0 | 27 | 1·0238 | 16·5 | 7·65 | 8·8 | 1·64 | 7·2 |
| 61 | L | 27 | 1 | 4 | 1·5 | 22 | 1·0327 | 11·8 | 2·40 | 9·4 | 2·32 | 7·1 |
| 76 | B | 27 | 1 | 5 | 0·5 | 14 | 1·0325 | 9·2 | 0·73 | 8·5 | 1·70 | 6·8 |
| 105 | R | 27 | 1 | 5 | 1·25 | 29 | 1·0312 | 9·4 | 1·01 | 8·4 | 1·54 | 6·8 |
| 25 | R | 27 | 1 | 5 | 4·25 | 20+ | 1·0318 | 11·2 | 2·22 | 9·0 | 1·78 | 7·2 |
| 119 | L | 27 | 1 | 8 | 2·0 | 11 | 1·0295 | 12·9 | 3·07 | 9·8 | 2·01 | 7·8 |
| 114 | B | 27 | 2 | 9 | 1·0 | 9 | 1·0313 | 12·5 | 3·23 | 9·3 | 1·62 | 7·6 |
| 22 | R | 28 | 2 | 3 | 2·75 | 20 – | ... | 13·1 | 3·10 | 10·0 | 2 02 | 8·0 |
| 109 | L | 37 | 2 | 6 | 1·0 | 15 | 1·0328 | 13·3 | 3·46 | 9·8 | 1·68 | 8·2 |
| 27 | R | ... | 2 | 4 | 4·75 | 20 – | ... | 11·2 | 1·63 | 9·6 | 1·97 | 7·6 |
| 34 | B | ... | 2 | 5 | 1·5 | 20+ | 1·0351 | 12·6 | 2·41 | 10·2 | 4·00 | 6·2 |
| 66 | R | 18 | 2 | 4 | 1·0 | 30 | 1·0318 | 11·9 | 2·86 | 9·0 | 1·85 | 7·2 |
| 112 | B | 18 | 2 | 6 | 5·5 | 15 | 1·0301 | 12·2 | 3·11 | 9·1 | 1·65 | 7·4 |
| 41 | L | 19 | 2 | 3 | 1·0 | 20+ | 1·0324 | 12·0 | 3·77 | 8·2 | 2·08 | 6·1 |
| 80 | L | 19 | 2 | 4 | 1·0 | 23 | 1·0337 | 12·1 | 2·76 | 9·3 | 1·28 | 8·1 |
| 45 | B | 19 | 2 | 5 | 0·5 | 14 | ... | 12·5 | 3·87 | 8·6 | 2·70 | 5·9 |
| 92 | R | 19 | 2 | 5 | 2·5 | 13 | 1·0351 | 11·6 | 1·83 | 9·8 | 2·67 | 7·1 |

| Number. | Breast. | Age of Mother. | Pregnancy. | Age of Child. | Hours since suckled. | Volume of sample. | Density. | Total solids. | Fat. | Solids not fat. | Protein. | Solids not fat nor protein. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 68 | L | 20 | 2 | 4 | 1·75 | 14 | .. | 12·8 | 3·20 | 9·6 | ... | ... |
| 58 | L | 21 | 2 | 4 | 1·25 | 17 | 1·0347 | 12·2 | 2·16 | 10·0 | 2·70 | 7·3 |
| 95 | L | 21 | 2 | 6 | 1·5 | ... | 1·0326 | 11·5 | 2·25 | 9·2 | 1·44 | 6·7 |
| 51 | R | 22 | 2 | 5 | 0·5 | 29 | 1·0332 | 10·9 | 1·46 | 8·4 | 2·11 | 7·3 |
| 20 | L | 22 | 2 | 5 | 2·0 | 20+ | 1·0295 | 12·2 | 1·64 | 10·6 | 1·60 | 9·0 |
| 33 | L | 22 | 2 | 2 | 7·5 | 20+ | 1·0344 | 12·2 | 2·50 | 9·7 | 2·39 | 7·3 |
| 54 | L | 23 | 2 | 4 | 9·25 | 28 | 1·0327 | 13·5 | 3·65 | 9·8 | 1·96 | 7·9 |
| 71 | L | 23 | 2 | 7 | 1·0 | 19 | 1·0349 | 11·9 | 2·05 | 9·8 | 1·94 | 7·9 |
| 74 | L | 24 | 2 | 4 | 5·25 | 11 | 1·0336 | 13·5 | 3·64 | 9·9 | 1·94 | 7·9 |
| 77 | R | 25 | 2 | 4 | 0·75 | 13 | 1·0300 | 13·2 | 4·15 | 9·0 | 1·92 | 7·1 |
| 115 | B | 26 | 2 | 2 | 2·0 | 9 | 1·0330 | 13·7 | 3·48 | 10·2 | 2·95 | 7·3 |
| 89 | L | 26 | 2 | 5 | 1·5 | 15 | 1·0310 | 13·6 | 4·08 | 9·5 | 1·68 | 7·8 |
| 65 | L | 26 | 2 | 5 | 2·0 | 24 | 1·0354 | 15·5 | 4·53 | 11·0 | 2·55 | 8·4 |
| 70 | L | 26 | 2 | 6 | 0·75 | 16 | 1·0293 | 14·9 | 3·14 | 11·8 | 2·01 | 9·7 |
| 79 | R | 27 | 2 | 5 | 1·0 | 9 | 1·0340 | 13·7 | 3·93 | 9·8 | 2·09 | 7·7 |
| 21 | L | 27 | 2 | 5 | 1·5 | 20 – | ... | 12·3 | 2·00 | 10·3 | 2·40 | 7·9 |
| 94 | L | 28 | 2 | 5 | 1·0 | ... | 1·0333 | 11·8 | 2·52 | 9·3 | 1·68 | 7·6 |
| 19 | L | 28 | 2 | 5 | 3·5 | 10+ | 1·0308 | 13·6 | 1·82 | 11·8 | 1·10 | 10·5 |
| 100 | R | 29 | 2 | 4 | 2·75 | 8 | 1·0296 | 12·6 | 3·48 | 9·1 | 3·92 | 5·2 |
| 107 | R | 30 | 2 | 3 | 1·0 | 10 | 1·0353 | 11·0 | . | ... | ... | . . |
| 111 | B | 30 | 2 | 5 | 1·0 | 11 | 1·0324 | 11·3 | 2·14 | 9·2 | 1·58 | 7·6 |
| 88 | R | 30 | 2 | 5 | 1·75 | 9 | 1·0298 | 11·6 | 4·22 | 7·4 | 1·30 | 6·1 |
| 120 | B | 30 | 2 | 9 | 1·5 | 35 | 1·0318 | 13·2 | 3·91 | 9·3 | 1·53 | 7·8 |
| 90 | B | 30 | 2 | 8 | 1·5 | 13 | 1·0335 | 12·6 | 2·81 | 9·8 | 1·32 | 8·5 |
| 122 | L | 30 | 2 | 8 | 8·75 | 20 | 1·0360 | 10·8 | 3·50 | 7·3 | 1·43 | 5·9 |
| 62 | L | 31 | 2 | 5 | 1·0 | 30 | 1·0368 | 13·2 | 2·48 | 10·7 | 3·58 | 7·1 |
| 87 | L | 32 | 2 | 3 | 3·5 | 23 | 1·0329 | 13·5 | 2·03 | 11·5 | 1·98 | 9·5 |
| 75 | L | 26 | 3 | 4 | 1·0 | 15 | 1·0358 | 10·8 | 1·21 | 9·6 | 2·44 | 7·1 |
| 29* | R | 28 | 3 | 2 | 8·25 | 20 – | ... | 18·6 | 2·63 | 16·0 | 4·10 | 11·9 |
| 43 | B | 30 | 3 | 4 | 0·5 | 22 | 1·0268 | 11·8 | 3·75 | 8·0 | 2·60 | 5·4 |
| 97 | R | 32 | 3 | 3 | 3·0 | 11 | 1·0307 | 13·6 | 4·12 | 9·5 | 1·16 | 8·3 |
| 78 | L | 34 | 3 | 4 | 2·0 | 21 | 1·0332 | 13·2 | 3·42 | 9·8 | 2·01 | 7·8 |
| 47 | B | 40 | 3 | 7 | 0·5 | 27 | 1·0313 | 12·9 | 3·97 | 8·9 | 2·04 | 6·9 |
| 50 | L | ... | 3 | 4 | 0·5 | 31 | 1·0301 | 9·9 | 4·14 | 5·8 | 2·78 | 3·0 |
| 85 | B | 26 | 4 | 8 | 1·0 | 18 | 1·0305 | 13·8 | 4·43 | 9·4 | 1·38 | 8·0 |
| 26 | L | 29 | 4 | 8 | 2·0 | 20+ | 1·0307 | 13·4 | 3·80 | 9·6 | 1·99 | 7·6 |
| 91 | R | 34 | 4 | 9 | 1·0 | 12 | 1·0307 | 13·7 | 4·41 | 9·3 | 0·99 | 8·3 |
| 59 | L | 42 | 4 | 4 | 1·0 | 17 | 1·0313 | 11·4 | 3·66 | 7·7 | 1·40 | 6·2 |
| 40 | B | 33 | 5 | 6 | 3·5 | 20 – | ... | 12·5 | 2·86 | 9·6 | 1·99 | 7·6 |
| 110 | R | 26 | 6 | 5 | 3·0 | 18 | 1·0343 | 11·2 | 1·82 | 9·4 | 1·71 | 7·7 |
| 81 | B | 30 | 6 | 4 | 1·0 | 12 | 1·0298 | 10·0 | 1·09 | 8·9 | 4·20 | 4·7 |
| 83 | B | 30 | 6 | 4 | 1·5 | 31 | 1·0329 | 12·5 | 3·80 | 8·7 | 2·17 | 6·5 |
| 56 | L | 30 | 6 | 5 | 0·5 | 26 | 1·0325 | 11·6 | 1·99 | 9·6 | 1·94 | 7·7 |
| 49 | L | 31 | 6 | 6 | 0·5 | 20 | 1·0297 | 10·6 | 2·39 | 8·2 | 2·30 | 5·9 |
| 118 | R | 31 | 6 | 8 | 1·0 | 35 | 1·0274 | 12·3 | 3·87 | 8·4 | 2·57 | 5·9 |
| 116 | L | 32 | 7 | 8 | 0·25 | 19 | 1·0318 | 12·2 | 2·25 | 9·9 | 1·91 | 8·0 |
| 84 | B | 32 | 9 | 9 | 1·0 | 11 | 1·0308 | 14·5 | 4·64 | 9·9 | 1·87 | 8·0 |
| 63 | L | 25 | multi-para | 6 | 1·0 | 14 | 1·0329 | 13·1 | 3·38 | 9·7 | 2·02 | 7·7 |
| 35 | B | 18 | . . | 4 | 1·5 | 20+ | 1·0316 | 10·9 | 1·77 | 9·1 | 3·93 | 5·2 |
| 18 | R | 21 | ... | 11 | 3·0 | 20+ | 1·0293 | 11·7 | 1·52 | 10·2 | 0·95 | 9·2 |
| 37 | B | 20 | . | 4 | 2·5 | 20+ | 1·0322 | 11·7 | 2·53 | 9·2 | 1·98 | 7·2 |
| 36 | B | 24 | ... | 4 | 4·0 | 20+ | 1·0339 | 13·0 | 3·02 | 10·0 | 3·21 | 7·8 |

Although the significance of the mean values of the results of a series of analyses such as the above is in general not so apparent as might be desired, the mean values of the results of the above series have been given, together with the maximum and minimum values, both for comparison with the results of other investigators, and because, as will be shown later, mean values may approach values having a definite significance when the number of observations is fairly large, as in the present case.

Table III.—*Maximum, mean, and minimum values of the density and composition of the samples of human milk examined.*

| | Density. | Total Solids. | Fat. | Solids not fat. | Protein | Solids not fat nor protein. |
|---|---|---|---|---|---|---|
| Maximum | 1·0370 | 15·5 | 7·65 | 12·2 | 4·2 | 11·9 |
| Mean | 1·0321 | 13·1 | 3·14 | 10·0 | 2·00 | 8·0 |
| Minimum | 1·0260 | 9·4 | 0·56 | 6·2 | 0·95 | 3·8 |

The results for sample 29, which was colostrum, are not included in the above table. The figures in the table show how widely separated are the limits between which the composition of the samples of human milk examined in the present case varied. The mean values, it will be noticed, are not very different from those of the investigators quoted at the beginning of the paper, with the exception of the values for the percentage of protein given by Camerer and Söldner (*loc. cit.*), which differ from the values given by the majority of other workers. It must be remembered, however, that the present results are for the milk of the first week of lactation only.

### 4. The most probable composition of human milk.

When a series of measurements of a certain quantity is made, the results of these measurements are found, in general, not to be identical, but to differ among themselves, even when the quantity measured is assumed to remain

unchanged. Under these circumstances, when the measurements are all made with equal care, there is no reason to believe that any one of them is nearer the truth than any other and the arithmetic mean of the whole number of measurements is taken as representing a value which is probably nearer to that of the quantity itself than the value obtained from any isolated measurement. The arithmetic mean of the results in this case has a very definite meaning.

But when the quantity measured itself varies, each value which it takes cannot be regarded as an equally probable approximation to a hypothetical "true" value, but itself has a real existence. To take the arithmetic mean of a series of measurements of such a quantity, then, is to obtain a figure which only has a meaning on the basis of assumptions which do not hold in this case. As the arithmetic mean of a series of measurements of a quantity which varies has thus, of itself, no significance, how then is a series of measurements of such a quantity to be briefly described? Attention seems to have been first directed to this question by Francis Galton (1879).

Quantities which are observed to vary are of two main types: (1) those whose variations bear a definite relation to the variations of a second quantity or group of quantities, and (2) those in which no such relation to other quantities has been detected. A series of measurements of a quantity of the first type may be briefly and completely described by stating the relation which exists between this quantity and the second quantity or group of quantities. Such a relation is expressed by the mathematical function which the values of the first quantity are of the values of the second quantity. Numerous intermediate stages occur between the extreme cases where all the values taken by one quantity are a function of the values of other quantities and where no definite relation has been discerned

between the values of the quantities associated together. Karl Pearson (1903) has regarded all phenomena as being, to a certain degree, contingent upon one another. In phenomena or quantities of the first type the degree of contingency is high, and may be expressed numerically as approaching unity, where a contingency of 1 represents absolute dependence. In phenomena or quantities of the second type the degree of contingency is low, and may be represented as approaching zero, where a contingency of 0 represents complete independence.

The values of the various quantities which may be measured in milk, the percentages of the various substances which occur in it, although they must *a priori* bear an intimate relation to one another, being produced together by living organism which we know by observations made in other directions to have a wonderful power of co-ordinating its activities, yet do not bear to one another a relation which we have so far been able to accurately and briefly define. The amounts of the different substances occurring in milk must therefore be regarded at present as bearing only a low degree of contingency to one another, and not very much information may be gained by the study of the relation between series of observations of such quantities, as will be seen later.

If, however, each of these series be examined separately, and the results be arranged according to their magnitude, the series may be found to be capable of being divided into two main classes: (1) those in which the numbers of results are fairly evenly distributed over the whole range of the values observed, or (2) those in which there is a certain value in whose vicinity the results are much more numerous than elsewhere, the numbers of results becoming smaller and smaller as this value is receded from in either direction. In a series of results of the first kind, any particular result

is, to all appearances, no more likely to occur than any other, and the values of the results obtained must, on the evidence at hand, all be regarded as equally probable. The only convenient way of summarising such a series of values is to take the arithmetic mean of them all. But the figure obtained by this process cannot be regarded as being likely to be nearer a "true" value of the quantity measured than any isolated result, as in the case discussed above, but is simply a number such that any particular result in the series is no more likely to be above it than below it.

But in the case of a series of the second kind, there is a value in the vicinity of which the results seem to be more likely to occur than in parts of the series further removed from this value. There is thus a greater probability that any result will fall in the vicinity of this value than anywhere else. Such a value may, therefore, be regarded as the most probable value of the quantity which is being observed.

The values obtained for the percentages of the various constituents in the samples of human milk analysed in the present work have been arranged according to their magnitude, as described above, and it has been found that both of these latter types of series are represented among them. In arranging a series of values according to their magnitude for examination in this way, the successive values must be so chosen as to increase by some convenient amount at each step, and in the present case the increment chosen for each step is one-tenth of the mean or most probable value of the series. If the steps chosen be too small, irregularities (not necessarily inaccuracies) in the values of the results obtained will obscure the general trend of the observations, while if the steps be too large, their number will be too few to adequately show the way in which the grouping of the results varies through the series.

In the following tables the percentages of the constituents of human milk are arranged in ascending order of magnitude, and under each value is given the number of results falling between this value and the succeeding one. Since, in the present case, the total number of results is about one hundred, these numbers represent the percentages of the total number of results falling between each pair of values, and may be considered as the relative probabilities of the occurrence of results having these particular values.

(1) *Fat*—The following are the relative frequencies of occurrence of the various percentages of fat observed in the samples of human milk examined.

| Percentage of fat | under 1·2 | 1·2 | 1·5 | 1·8 | 2·1 | 2·4 | 2·7 | 3·0 | 3·3 | 3·6 | 3·9 | 4·2 | 4·5 and over |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of results | 5 | 3 | 4 | 9 | 9 | 13 | 10 | 9 | 11 | 8 | 11 | 6 | 6 |

From these figures it will be seen that in the case of the fat of the samples of human milk examined, the results show no tendency to group themselves about any particular value, but occur with fairly even frequency over the greater part of the values observed. No most probable value for the percentage of fat can therefore be stated from these results, and the only easily obtained figure of general significance for the whole series is the arithmetic mean of the results, 3·14%.

(2) *Protein*—The following are the relative frequencies of occurrence of the various percentages of protein observed in the samples.

| Percentage of protein | 0·8 | 1·0 | 1·2 | 1·4 | 1·6 | 1·8 | 2·0 | 2·2 | 2·4 | 2·6 | 2·8 | 3·0 | 3·2 and over |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of results | 2 | 2 | 7 | 7 | 17 | 18 | 13 | 7 | 9 | 6 | 3 | 1 | |

It will be seen from these figures that samples of milk having percentages of protein between 1·6 and 2·2 were

much more frequent than samples having any percentage outside of these limits. About 50% of the total number of results occur between these values and as they are fairly evenly distributed within the limits, their mean value 1·9 may be taken as representing the most probable percentage of protein in the human milk examined.

(3) *Solids not fat and not protein*—The following are the relative frequencies of occurrence of the various percentages of solids not fat and not protein in the samples. Over 90% of this portion of the milk, it will be remembered, is composed of milk-sugar.

| Percentage of solids not fat nor protein | 3·8 | 4·5 | 5·2 | 5·9 | 6·6 | 7·3 | 8·0 | 8·7 | 9·4 | 1·1 |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of results | 3 | 3 | 4 | 10 | 16 | 37 | 19 | 2 | 2 | 3 |

From these figures it will be seen that samples of milk having percentages of solids not fat and not protein between 6·7 and 8·7 occur more frequently than samples having any percentage outside of this range, and the mean of this range of values, 7·6, may be regarded as the most probable value of the percentage of solids not fat and not protein in the samples of human milk examined. About 60% of the total number of results occur within this range. The closeness with which the results are grouped about a certain value is greater in this case than the case of the percentages of protein.

The values of the percentages of the other portions of human milk which are considered as being of importance, of the total solids and of the solids not fat and are determined by the values of the constituents just given. The percentages of total solids and of solids not fat are given separately below.

(4) *Total solids*—The following are the relative frequencies of occurrence of the various percentages of total solids in the samples examined.

| Percentage of total solids | 8·3 | 9·6 | 10·9 | 12·2 | 13·5 | 14·8 | 15·1 and over |
|---|---|---|---|---|---|---|---|
| Number of results | 3 | 12 | 24 | 45 | 15 | 3 | 2 |

It will be seen from these figures that samples of milk having percentages of total solids between 10·9 and 14·8 are of considerably more frequent occurrence than samples having a percentage outside of this range. The mean of this range, 12·8% may therefore be considered as the most probable percentage of solids for the series. The results are even more closely grouped about this value than in the previous case, over 80% of the results occurring within an equal range. These figures also indicate that the occurrence of percentages of total solids above this value is rather less likely than the occurrence of percentages below it, as the numbers of results are not quite symmetrically arranged about the most probable value but lower values are more plentiful than higher values.

(5) *Solids not fat*—The following are the relative frequencies of occurrence of the various percentages of solids not fat observed in the samples of human milk examined.

| Percentage of solids not fat | 6·3 | 7·2 | 8·1 | 9·0 | 9·9 | 10·8 | 11·7 |
|---|---|---|---|---|---|---|---|
| Number of results | 3 | 6 | 17 | 55 | 16 | 2 | 3 |

These figures show that samples having percentages of solids not fat between 8·1 and 10·8 are much more frequent than those having any percentage outside this range. Nearly 90% of the total number of results occur between these limits. The mean of this range of values, 9·4%, may therefore be considered as the most probable value of the percentage of solids not fat of these samples of human milk. It will be noticed that the numbers of results are much more closely grouped about the most probable value in this than in any of the other cases studied. This is another way of expressing the generally recognised

fact that solids not fat of milk are much more constant in amount than any of the other constituents usually determined.

The distributions of these results over the ranges of values observed are represented graphically in the accompanying diagram. In this diagram the percentage deviations of the results from the most probable value have been plotted as abscissæ, the percentages of the total number of the results showing these deviations as ordinates.

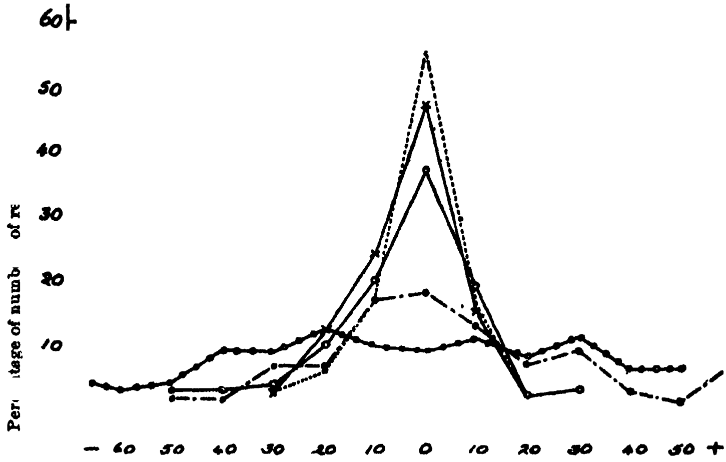


Diagram showing the distributions of the percentages of the constituents of human milk over the ranges of values found.

O —— O —— O = fat.
● —— - —— ● = protein.
O ———— O = solids not fat and not protein.
× ———— × = total solids.
- - - - - - - - - = solids not fat.

This diagram shows very clearly how the results tend towards certain values in the case of all of the constituents of human milk estimated, with the exception of the fat. The different degrees of closeness with which the results

are grouped about the most probable values are also well shown by the different heights of the maxima on the curves, and the different degree of steepness with which they rise to these maxima.

The striking difference between the distribution of the percentages of fat and those of the percentages of the other constituents is not peculiar to the present results, but is equally well shown by the results of Leeds, Carter and Droop Richmond, and Camerer and Söldner already quoted in this paper. The following are the relative frequencies of occurrence of the various percentages of fat recorded in their papers arranged as described above. In these cases, of course, since the total numbers of results are not one hundred, the numbers given do not represent percentages.

| Per-cent. of fat. | 1·5 and under | 1·8 | 2·1 | 2·4 | 2·7 | 3·0 | 3·3 | 3·6 | 3·9 | 4·2 | 4·5 | 4·8 | 5·1 | 5·4 and over |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of results | *1 | 3 | 2 | 5 | 6 | 6 | 9 | 7 | 2 | 5 | 3 | 0 | 2 | 1 |
| | †0 | 0 | 3 | 3 | 6 | 6 | 2 | 7 | 5 | 5 | 3 | 4 | 0 | 13 |
| | ‡16 | 6 | 6 | 10 | 6 | 11 | 9 | 9 | 7 | 3 | 3 | 2 | 1 | 4 |

* Camerer and Söldner. † Leeds. ‡ Carter and Droop Richmond.

As will be seen from these figures, the results show practically no tendency to group themselves about any particular value but occur with fairly even frequency over a wide range of values.

When, however, the percentages of the other constituents are arranged in the same way they are found, as in the case of the results of the present work, to group themselves about certain values with varying degrees of closeness.

The process by which the fat of human milk is secreted, therefore, unlike the processes by which the other constituents are produced, does not seem to favour the appearance of milk containing any particular percentage more than any other between certain wide limits. Although it might be contended that the irregularities found in the

percentages of fat in human milk may be due to a faulty method of obtaining the samples, it seems fairly evident that the fat of the milk is secreted by a process which is more less independent of that by which all the other constituents are produced, and the samples obtained for analysis must surely be comparable with the samples obtained by a suckling child, which can hardly be regarded as regulating to a nicety both the intervals between its meals, and the quantities which it takes. The chief object of the analysis of human milk is, after all, to ascertain the composition of the food of the human infant.

In the table given below the values for the most probable percentages of the various constituents of human milk obtained from the results of the present work and from those of the work of the authors quoted are placed together. The values of the mean percentages are also given for comparison.

Table IV.—*Most probable and mean values of percentages of constituents of human milk.*

| Author. | Total Solids. | | Solids not fat | | Protein. | | Sug | |
|---|---|---|---|---|---|---|---|---|
| | Mean. | Most probable. | Mean. | Most prob. | Mean. | Most prob. | Mean. | Most prob. |
| Leeds ... | 13·3 | 13·0 | 9·1 | 9·3 | 2·0 | 2·0 | 6·9 | 7·1 |
| Carter and Droop Richmond | 12·0 | 11·7 | 8·9 | 8·6 | 2·0 | 1·7 | 6·6 | 6·9 |
| Camerer and Söldner | 12·0 | 12·0 | 8·6 | 8·7 | 1·4 | 1·1 | 6·4 | 6·7 |
| Halcro Wardlaw | 13·1 | 12·8 | 10·0 | 9·8 | 2·0 | 1·9 | 4·7 | 7·1 |

From the above table it will be seen that the results obtained in these four series of analyses, with the exception of the percentage of protein given by Camerer and Söldner, do not differ materially from one another. It would appear, therefore, that climate has no very marked effect on the composition.

These figures show also that the mean values of the results do not differ much, as a rule, from the most probable values. This is due to the fact that the results lying outside the range of most probable values are fairly evenly distributed on either side, and so balance when the arithmetic mean of the whole is taken. The arithmetic mean of series of analyses such as these, although of itself it has no meaning, thus lies close to a value which has a definite significance, and the mean value may, therefore, be used in many cases instead of the better defined, but not so readily accessible, most probable value. It should be remembered, however, that the occurrence of a number of very high or low values in a series of results would considerably alter the mean of the series, but not the most probable value.

**5. Variation of composition with time since parturition.**

The composition of a sample of human milk is known to depend on the stage of lactation of the woman from whom it is obtained (Schloss, 1912; Camerer and Söldner, Engel, Adriance and Adriance, *loc. cit.*). The main features of this dependence are that the ash and protein of the milk tend to decrease as the lactation continues, while the amount of milk sugar slightly increases. These statements apply to the very gradual alteration in the composition of human milk during the course of months of lactation. During the first few days of lactation, however, the alteration in the composition must be very much more rapid, since the milk first secreted after the birth of the child, the colostrum, has a composition which differs considerably from that of the milk secreted later, the principal difference being the high percentage of protein in the former. Sample No. 29, Table II, is a typical example of colostrum. The variation of the composition of human milk obtained in the first few days after the colostral period, which

normally does not last longer than forty-eight hours, does not seem to have been examined in detail. Practically all of the human milk, the analyses of which are given in this paper, were obtained during this immediately post-colostral period, and the results of these analyses have been arranged in the following table so as to indicate how the average composition alters during these first few days of lactation. The samples from which the table has been compiled were obtained from women who had been suckling for periods ranging from two to eleven days.

Table V.—*Variation of composition of human milk with stage of lactation.*

| Suckling for | Number of samples | Density. | Total solids. | Fat. | Solids not fat. | Protein. | Solids not fat nor protein. |
|---|---|---|---|---|---|---|---|
| 1 – 2 days | 3 | 1·0337 | 14·8 | 2·84 | 12·0 | 3·30 | 8·7 |
| 3 – 4 ,, | 39 | 1·0322 | 12·2 | 2·84 | 9·4 | 2·33 | 7·0 |
| 5 – 6 ,, | 36 | 1·0320 | 12·2 | 2·64 | 9·6 | 2·06 | 7·5 |
| 7 – 8 ,, | 13 | 1·0319 | 12·3 | 3·27 | 9·0 | 2·02 | 7·0 |
| 9 – 11 | 11 | 1·0308 | 13·5 | 4·13 | 9·4 | 1·69 | 7·7 |

It will be seen from this table that the average values of the density and protein fell during the period of observation; the fat remained almost constant for a time and then rose considerably; the amount of total solids fell rapidly at first, this fall being due to the large decrease in the amount of protein associated with the disappearance of colostrum, then rose again as the amount of fat present increased; the amount of solids not fat fell rapidly at first, and then fluctuated slightly, but did not move steadily in any direction; the amount of solids not fat and not protein varied in the same way as the amount of solids not fat. On the whole the composition did not alter materially after the second day. The author hopes to deal with the later stages of lactation in detail in a subsequent paper. The

great majority of the samples dealt with in the present paper were obtained four to five days after the commencement of suckling.

### 6. Effect of age of woman on composition of milk.

In the samples of human milk which Leeds (*loc. cit.*) examined, he found that the average composition of the milk of women under twenty years of age showed higher values in the amount of every constituent than the milk of women over twenty years of age. In the following table the average compositions and densities of the human milks examined in the present investigation are arranged according to the ages of the women from whom they were obtained. The samples obtained from primiparæ have been kept separate from those from multiparæ.

Table VI.—*Effect of age on composition of human milk.*

| Age. | Primiparæ. | | | Multiparæ. | | |
|---|---|---|---|---|---|---|
| | 20 and under. | 21 to 30 | 31 and over | 20 and under | 21 to 30 | 31 and over |
| No. of results | 15 | 28 | 1 | 8 | 37 | 12 |
| Density ... | 1·0319 | 1·0323 | ... | 1·0326 | 1·0319 | 1·0314 |
| Total solids ... | 12·4 | 12·2 | 13·3 | 12·1 | 12·9 | 12·1 |
| Fat ... ... | 3·15 | 2·67 | 3·46 | 2·87 | 2·98 | 2·97 |
| Solids not fat | 9·4 | 9·5 | 9·8 | 9·2 | 9·9 | 9·4 |
| Protein ... | 1·91 | 2·06 | 1·68 | 1·88 | 2·40 | 1·96 |
| Solids not fat nor protein | 7·7 | 7·1 | 8·1 | 7·3 | 7·5 | 7·4 |

No very clear evidence of a definite relation between the age of a woman and the composition of the milk secreted by her seems to be shown by the above figures. There is some evidence, however, that the percentage of protein is higher in the milk of women between the ages of 20 and 30 than in the milk of women younger or older than this in the case of primiparæ as well as in that of multiparæ.

**7. Percentage of fat in milk of each breast.**

It has been supposed by certain investigators that there is a constant difference between the average percentages of fat in the milk obtained from each breast. Mendes de Leon (*loc. cit.*) states that the milk of the right breast is richer in fat than that of the left, while Zappert and Jolles (1903) found the milk of the left breast to contain up to 0·6% more fat than that of the right breast. The samples of milk examined in the present case have been compared together to determine whether any such difference between the secretions of the two breasts is to be seen in them. All of the samples compared were of the milk secreted at the same stage of lactation (4–5 days *post partum*). The average percentage of fat in the milk of the right breast (19 samples) was found to be 2·57; the average percentage of fat in the milk of the left breast (22 samples) was found to be 2·50. In view of the large variations in the percentage of fat in the samples of human milk examined, however, the difference between these two figures (0·07%) is too small to justify a conclusion that the average percentage of fat in the milk of one breast is persistently higher than that of the milk of the other breast.

**8. Effect of number of pregnancies on composition of human milk.**

In the following table are given the average values of the density and composition of the milk of women at the first, second, third, and subsequent pregnancies.

Table VII.—*Effect of number of pregnancies on composition of human milk.*

| Number of pregnancies | 1 | 2 | 3 | More than 3 |
|---|---|---|---|---|
| Number of samples ... | 46 | 33 | 20 | 13 |
| Density ... ... ... | 1·0324 | 1·0328 | 1·0312 | 1·0309 |
| Total solids ... ... | 12·2 | 12·6 | 12·6 | 12·5 |
| Fat ... ... ... | 2·91 | 3·04 | 3·44 | 3·32 |
| Solids not fat ... ... | 9·4 | 8·6 | 8·1 | 9·1 |
| Protein ... ... ... | 2·01 | 2·14 | 2·17 | 1·89 |
| Solids not fat nor protein | 7·4 | 6·4 | 6·4 | 7·2 |

From this table it will be seen that the average density is highest at the second pregnancy, and falls as the number of pregnancies increases; the average percentage of total solids is slightly lower at the first pregnancy than at the subsequent; the average percentage of fat rises till the third pregnancy, and then begins to fall; the average percentage of solids not fat is higher at the first than at subsequent pregnancies, although there is a rise after the third; the average percentage of protein, like that of the fat rises, until the third pregnancy and then falls; while the average percentage of solids not fat and not protein, falls after the first pregnancy, but increases again after the third.

### 9. Effect of volume of sample and of period of rest on fat-content of human milk.

With regard to the effect of the volume of a sample of human milk obtained from the breast one might expect from the work of Engel and others quoted in this connection that, in general, the smaller the volume of a sample was the higher the percentage of fat in it would be. In the present case, when the volume of the sample was between 15 cc. and 24 cc. the average percentage of fat was 2·66; and when the volume of the sample was between 25 cc. and 35 cc. the percentage of fat in it was 3·09. These figures are more in accord with the statement of Helbich (*loc. cit.*) than with that of Engel, and show no very evident reciprocal relation between the volume of the sample and the percentage of fat in the milk.

The effect of the time of rest since the last withdrawal of milk from the mammary gland on the percentage of fat in the milk yielded should be similar, according to the workers cited above, to that of the volume of the sample, that is, the relation should be an inverse one. When samples of milk of approximately equal volume, but obtained

after different periods of rest, were compared in the present case, it was found that after half an hour the percentage of fat was 3·07; after one hour it was 2·95, and after that fluctuated irregularly. No definite relation between the time of rest of the mammary gland and the percentage of fat of the milk yielded is apparent, therefore, from these results.

## 10. Summary.

1. Certain values of the percentages of constituents other than fat of human milk of the first week *post partum* occurred much more frequently than others. These values were:—total solids, 12·8; solids not fat, 9·8; protein, 1·9; solids not fat and not protein, 7·6.

2. There was no definite percentage of fat near which the percentages in the majority of the samples lay, but the results were fairly evenly distributed over the whole range of values found. The average percentage of fat was 3·14.

3. The average percentage of fat increased from 2·84 to 4·13 during the first eleven days of suckling; the average percentage of protein decreased from 3·30 to 1·69 during the same period.

4. The age of the woman, the number of pregnancies, the volume of the sample, the time since the last withdrawal of milk from the breast, and the breast from which the sample was taken, appeared to have no distinct effect on the composition of the milk examined.

5. A new method for the estimation of protein in milk has been described.

In conclusion, I wish to express my thanks to Professor Sir Thomas Anderson Stuart, in whose laboratory this work was carried out, and to Dr. H. G. Chapman for his advice and helpful suggestions.

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[*From the Proceedings of the Linnean Society of New South Wales. 1915, Vol. xl., Part 2, June 30th.*]

# THE TEMPERATURE OF *ECHIDNA ACULEATA*.*

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(With eight Text-figures.)

*Introduction.*—The study of the morphology of Echidna has led to its being classified with the most primitive of mammals. This fact has, perhaps, given rise to the supposition that the functional activities of the animal would share the primitive characters of its structure; and, indeed, Chapman(4) has shown that the behaviour of the muscle of the Echidna towards stimuli resembles more that of the muscle of cold-blooded animals such as the frog, than that of typical mammalian muscle. The observations which had, up to the present, been made of the temperature of Echidna were interpreted as further justifying this supposition.

The temperatures of reptiles lie within a few tenths of a degree of that of the surrounding air [Pembrey(10), Richet(11), Soetbeer(14)]. They vary, therefore, from day to day with the changes of the external temperature.

The temperatures of birds and of nearly all mammals (including marsupials) are subject to little variation (Pembrey, Richet, *loc. cit.*), and are maintained at levels (36°-45°C.), above which, in most parts of Australia, the temperature of the air rises only during a short season of the year [Hunt(8)].

The temperature of Echidna, however, was found to be considerably lower and more variable than that of other mammals. N. de Miklouho-Maclay(9), who appears to have been the first to observe the temperature of this animal (1879), found the cloacal

* The work, of which this paper is an account, was carried out in the year 1914, during the author's tenure of a Science Research Scholarship at the University of Sydney.

temperatures of two specimens to be 28·3° and 26·95°C. R. von Lendenfeld(6) gives the ordinary blood-temperature of the animal as 28°C., although he says it may rise as high as 35°C. Semon(13) found that the cloacal temperatures of the seven Echidnas, which he was able to observe, ranged from 26·5° to 34·0°C., whilst Sutherland(15), observing fourteen animals, found temperatures ranging from 22° to 36°C. The two latter observers recorded the temperatures of the air as well as those of the animals. The only conclusions to be drawn from the above small number of observations seem to be those expressed by Semon, that Echidna is not strictly to be classed either with poikilothermal or with homoiothermal animals; it has a body-temperature which stands in no direct relation to the temperature of the external air, but which undergoes uncommonly large variations.

Later, C. J. Martin(7) studied the behaviour of the temperature of Echidna, when the external temperature was rapidly varied in a definite and regular manner. Under these circumstances, it was shown that the temperature of Echidna undoubtedly depended on that of the surroundings. In experiments on three animals, for example, when the temperature of the surroundings rose from 5° to 35° in 6-7 hours, the temperature of the Echidnas rose from 25·5° to 34·8°, or 9·3°C., from 27·6° to 40·0°, or 12·4°C., and from 29·1° to 37·1°, or 8·0°C., respectively. It must be noted, however, that under circumstances such as these even the temperatures of higher mammals showed a degree of dependence on the external temperature much greater than usual. In the case of a rabbit, when the air-temperature fell from 40° to 5°, or 35°C., in about five hours, the temperature of the animal fell from 41·6° to 37·5°, or 4·1°C., in the same time. In the case of a cat, when the same fall in the external temperature occurred in an equal time, the temperature of the animal fell from 39·9° to 38·5°, or 1·4°C. The variations of the temperatures of reptiles (blue-tongued lizards) in similar experiments followed exactly those of the temperature of the surrounding air.

Under the conditions of these experiments, therefore, Echidna behaved in a manner intermediate, with regard to the regulation of its temperature, between that of reptiles and that of mammals;

and Martin concluded that Echidna is the lowest on the scale of warm-blooded animals.

But there is a class of mammals whose temperatures are at times subject to very great variations - the class of hibernants. The members of this class are not confined to any one group of animals, and among them is to be numbered Echidna (N. de Miklouho-Maclay, Martin, *loc. cit.*). During the winter-months, animals of this class allow their temperatures to sink towards that of the external air, and behave like cold-blooded animals for periods of varying duration.

As to the temperatures of these animals outside of the periods of hibernation, the data available are rather few in number, and different observers are not unanimous in their opinions. Pembrey (*loc. cit.*) states that, with regard to temperature, the behaviour of hibernants in their waking-state is practically the same as that of other warm-blooded animals. Merzbacher(8), on the other hand, is of the opinion that the temperature of hibernants in their waking-state is rather lower than that of other mammals, and is subject to much greater variations. He cites his own observations and those of Saissy(12, who gives the waking-temperature of the bat as 31°C; Berthold(3), who states that the normal waking-temperature of the dormouse is 29·7°C.; Barkow(2), who observed temperatures ranging from 25° to 35°C. in the case of a waking hedgehog; and of several other investigators in support of this view. A quotation from Barkow may be given as summarising their position: "Obgleich die Tiere ausserhalb des Winterschlafes zu den Warmblütigen gehören, so zeigt die Lebenswärme doch bei verminderter allgemeiner Tätigkeit, wie während des gewöhnlichen Schlafes, bei Abmagerung, oder sonstiger Krankheit, *grosse Neigung zum Sinken.*" Athanasiu(1), however, while admitting that the waking-temperatures of hibernants are perhaps slightly lower than those of other mammals, throws doubts on the reliability of the low figures given by some of the above observers, and points out how extremely limited is our knowledge of the temperatures of hibernants in their active state, and how necessary are new investigations to give us satisfactory information on this question.

In view of this incomplete state of our knowledge of the waking-temperatures of other hibernants, therefore, the conclusion that Echidna is the lowest on the scale of warm-blooded animals seems hardly justified. Anatomically, Echidna is indeed the most primitive of mammals, but between the anatomical classification of animals and their physiological functions there is not necessarily a direct relation. With regard to temperature, for example, this is well illustrated by a comparison of birds with reptiles and with mammals. As far as their structure is concerned, birds are much more closely related to reptiles than to mammals, and yet their behaviour with regard to temperature is quite different from that of reptiles, and very similar to that of mammals.

The aim of the present work has been to collect a series of observations of the body-temperature of Echidna under conditions which, although they can hardly be called natural, yet underwent no arbitrary, regular variations. The endeavour has also been made, by collecting a large number of data over fairly long periods and at different times of the year, to obtain material from which a more comprehensive idea of the behaviour of Echidna, with regard to temperature, might be gathered.

It may be stated here (i.) that the Echidnas under my observation hibernated only for very short periods at a time during the winter, (ii.) that, outside the periods of hibernation, their temperature kept in the neighbourhood of a value (30°C.) which is considerably lower than that of the average temperature of the majority of mammals, and (iii.) that the temperature of the animals was subject to comparatively large variations, and seemed to be affected, to some extent, by the temperature of the air.

*Methods.*—The observations recorded in this paper were made upon ten Echidnas, all males, and varying in weight from about 600 to about 2000 gms. The animals were kept in a shed of fibro-cement, the floor of the shed being of concrete, and having upon it a layer of sawdust about 5 cm. thick. For the first three weeks during which observations were made, the animals were fed upon bread and milk; for the remainder of the time, upon eggs beaten up with milk to which a little sodium citrate had

been added to hinder coagulation. These animals are apt to so gorge themselves upon milk (they are able to drink as much as 30% of their body-weight of it) that, if clotting be allowed to take place unhindered, a solid mass, which digests very slowly, is formed in the stomach and eventually causes death.

Of the ten Echidnas under observation, Nos. 1-7 were caught in Autumn, Nos. 8-10 in Spring. These animals survived for varying lengths of time, after coming under observation, as set forth in tabular form below.

| Caught in Autumn (April) 1914. | Caught in Spring (October) 1914. |
|---|---|
| No. 1 lived for 37 days. | No. 8 lived for 10 days. |
| No. 2 lived for 75 days. | No. 9 lived for 18 days. |
| No. 3 lived for 61 days. | No. 10 lived for 32 days. |
| No. 4 lived for 32 days. | |
| No. 5 lived for 103 days. | |
| No. 6 still living. | |
| No. 7 lived for 97 days. | |

It will be noticed that the animals captured in Autumn lived, on the average, much longer than those taken in Spring. No. 6 had been living in captivity for about twelve months at the time of writing. The death of one of the animals was due to acute peritonitis. What caused the death of the others is not known, although *post mortem* examinations showed the presence of infarcts in the liver in several cases. The animals were all rather emaciated before they died.

The body-temperatures of the animals were observed by inserting the bulb of a thermometer, graduated in tenths of a degree Centigrade, through the cloaca into the rectum, and reading off the temperature *in situ* to the nearest tenth of a degree after the lapse of two minutes, the time required for the mercury to become steady. The errors of the thermometers used were determined by reference to standard instruments, and the necessary corrections made to the readings. The animals were held up by a hind leg while the temperature was being observed. Difficulty was experienced at first in getting the thermometer into the rectum, owing to the rolling-up of the animals, but they soon became accustomed to handling, and then offered little resistance.

The temperatures of the animals were observed during two periods of the day, in the morning between 10 a.m. and 11 a.m., and in the afternoon between 2 p.m. and 3 p.m. The temperature of the air in the animals' shed, at a height of about 120cm. from the floor, was always read just before taking the temperature of the animals. It should be remarked that the temperature of the air above the animals may be considerably different from that of the sawdust covering the floor of the shed. On one hot day, for example, the temperature of the air was 37·4°C., whilst that of the sawdust was only 21·9°C.

*Results* —The following is a tabular record of the observations made.

TABLE i.

*Autumn and winter temperatures of Echidna.*

| Date. | Time. | Air-temp. | Temperature of Echidna No.1. | No.2. | No.3. | No.4. | No.5. | No.6. | No.7. |
|---|---|---|---|---|---|---|---|---|---|
| 30/4 | 10.15 | 20·2 | 30·8 | 29·8 | 31·6 | 29·1 | 31·6 | 28·3 | 28·5 |
| | 3.10 | 23·7 | 32·5 | 31·8 | 34·0 | 33·7 | 34·2 | — | 32·9 |
| 1/5 | 10.30 | 20·2 | 29·3 | 29·5 | 30·3 | 26·5 | 29·4 | 30·0 | — |
| | 2.30 | 22·2 | 31·8 | 32·4 | 33·3 | 30·9 | 33·4 | 32·0 | 33·0 |
| 4/5 | 11.0 | 20·2 | 30·0 | 31·9 | 30·1 | 25·9 | 30·3 | 29·9 | 30·2 |
| | 2.15 | 20·7 | 32·2 | 30·9 | 32·7 | 30·4 | 33·4 | 32·7 | 32·7 |
| 5/5 | 10.30 | 18·4 | 29·0 | 32·1 | 28·9 | 25·6 | 30·5 | 29·3 | 29·8 |
| | 2.30 | 20·4 | 31·6 | 31·3 | 32·7 | 30·2 | 33·7 | 30·8 | 32·9 |
| 6/5 | 10.30 | 18·6 | 27·7 | 30·7 | 31·2 | 23·2 | 29·7 | 29·0 | 29·8 |
| | 2.30 | 20·8 | 31·2 | 31·8 | 32·5 | 28·7 | 33·4 | 31·6 | 33·1 |
| 7/5 | 10.30 | 18·6 | 27·4 | 30·5 | 29·7 | 23·8 | 30·4 | 29·1 | 28·8 |
| | 2.0 | 19·8 | 29·8 | 32·9 | 33·2 | 29·4 | 33·3 | 30·3 | 32·5 |
| 8/5 | 10.15 | 20·3 | 26·8 | 30·3 | 30·4 | 25·1 | 29·3 | 29·3 | 29·4 |
| | 2.15 | 20·7 | 27·6 | 33·2 | 33·4 | 29·9 | 33·4 | 32·0 | 33·2 |
| 11/5 | 10.15 | 17·7 | 28·2 | 29·4 | 29·1 | 24·1 | 30·0 | 29·0 | 28·2 |
| | 2.30 | 19·9 | 31·4 | 32·9 | 33·4 | 29·0 | 33·3 | 32·0 | — |
| 12/5 | 10.30 | 17·6 | 29·2 | 30·0 | 27·4 | 25·0 | 29·4 | 28·6 | 29·9 |
| | 2.45 | 20·2 | 32·1 | 33·2 | 32·7 | 28·9 | 33·6 | 32·2 | 32·8 |
| 14/5 | 10.45 | 18·7 | 27·6 | 29·8 | 30·2 | 23·8 | 30·3 | 30·9 | 29·9 |
| | 3.15 | 19·7 | 32·1 | 33·4 | 32·8 | 29·0 | 33·5 | 33·5 | 33·3 |
| 15/5 | 10.45 | 17·2 | 28·8 | 30·5 | 26·1 | 24·9 | 29·3 | 29·7 | 29·5 |
| | 2.45 | 19·7 | 31·9 | 31·8 | 31·9 | 28·2 | 31·6 | 32·5 | — |
| 18/5 | 11.0 | 19·3 | 27·4 | 31·2 | 31·8 | 19·6 | 31·0 | 30·3 | |
| | 3.0 | 18·3 | 31·0 | 32·4 | 33·2 | 21·5 | 33·1 | 32·5 | Lost |
| 19/5 | 10.45 | 16·5 | 21·5 | 30·3 | — | 16·4 | 31·2 | 29·7 | |
| | 3.15 | 18·2 | 27·6 | 33·1 | — | 17·4 | 32·8 | 32·4 | |
| 20/5 | 10.30 | 17·3 | 21·5 | 30·0 | 26·9 | 16·6 | 29·6 | 28·6 | 20·0 |
| | 2.30 | 17·8 | 26·6 | 33·0 | 31·8 | 17·1 | 32·8 | 32·3 | 31·2 |
| 21/5 | 11.0 | 15·3 | 25·1 | 30·0 | 27·2 | 16·4 | 29·2 | 28·9 | 23·4 |
| | 2.45 | 17·0 | 28·9 | 32·6 | 32·0 | 22·8 | 32·0 | 32·1 | 29·2 |

TABLE I.—*Continued.*

| Date. | Time. | Air-temp. | Temperature of Echidna No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. | No. 7. |
|---|---|---|---|---|---|---|---|---|---|
| 22/5 | 10.30 | 16·4 | 26·6 | 29·0 | 27 0 | 24·6 | 31·5 | 29 6 | 26·1 |
| | 2.45 | 17·2 | 30·9 | 33·1 | 32·4 | 28·8 | 33·6 | 32·6 | 32·1 |
| 25/5 | 10.15 | 14·8 | 15·0 | 29·2 | 19·2 | 14·8 | 26·8 | 30·0 | 14·8 |
| | 2.30 | — | Hibernating, not disturbed. | 33·2 | 30·6 | Hibernating, not disturbed. | 32·7 | 32·3 | Hibernating, not disturbed. |
| 26/5 | 10.30 | 16·1 | | 29·3 | 26·2 | | 29·6 | 27·1 | |
| — | — | — | | — | | | — | — | |
| 27/5 | 10.30 | 13·2 | | 25·1 | Hibernating, not disturbed. | | 18·0 | 25·3 | |
| | 3.0 | 14·1 | | 32·5 | | | 31·1 | Hurt, not disturbed. | |
| 28/5 | 10.30 | 11·9 | | 28·5 | | | 25·3 | | |
| | 2.15 | 15·9 | | 32·8 | | | 32·2 | | |
| 29/5 | 10.30 | 13·7 | | 26·1 | | | 18·3 | | |
| | — | 16·6 | | 32 9 | | | — | | |
| 1/6 | 11.15 | 14·8 | 23·6 | 30·6 | 22 8 | dead | 29·5 | 22·2 | 28·8 |
| | 2.45 | 16·3 | 23·5 | 32·4 | 27·8 | ... | 27·2 | 29·9 | 32·6 |
| 2/6 | 10.15 | 12·9 | 15·7 | 25·2 | 15·8 | ... | 17·1 | 30·0 | 31·7 |
| | 2.45 | 17·2 | 16·2 | 32·5 | 19·1 | ... | 16·9 | 30·4 | 33·0 |
| 3/6 | 10.15 | 12·8 | 13 5 | 25·5 | 14·8 | ... | 12·8 | 23·8 | 21·9 |
| | 2.30 | 16 2 | 15·2 | 32·5 | 18·8 | .. | 14·7 | 31·0 | 31·7 |
| 4/6 | 10.30 | 11·2 | 12·4 | 19·4 | 13·9 | ... | 11·1 | 18·3 | 15·1 |
| | 2.45 | 16·0 | 14·5 | 31·8 | 21·7 | ... | 13 9 | 29 5 | 18·9 |
| 5/6 | 10.30 | 13 3 | dead | 20·2 | 20·3 | ... | 25·7 | 29·1 | 17·2 |
| | 2.45 | 16·9 | ... | 30·8 | 32·1 | ... | 32·0 | 31·5 | 31·0 |
| 9/6 | 11.0 | 13 7 | ... | 20·9 | 17·9 | ... | 19·6 | 17·7 | 19·4 |
| | 2.15 | 17·2 | ... | 30·9 | 22·0 | ... | 29·0 | 22 3 | 20·7 |
| 10/6 | 10.45 | 13·4 | ... | 26·1 | 14·9 | ... | 16·5 | 17·2 | 16·1 |
| | 2.30 | 16·5 | ... | 32·5 | 15·8 | .. | 29·1 | 29 5 | 15·8 |
| 11/6 | 10.15 | 13·2 | ... | 30·4 | 13 5 | ... | 25·3 | 29·6 | 13·8 |
| | 2.15 | 15·5 | ... | 33·1 | 14·8 | ... | 25·5 | 32·0 | 26·8 |
| 12/6 | 10.15 | 11·8 | ... | 29·6 | 12·4 | ... | 25·3 | 23·4 | 30·0 |
| | 2.15 | 15·4 | ... | 32·7 | 14·7 | ... | 27·8 | 30·5 | 32·0 |
| 15/6 | 10.30 | 12·0 | .. | 14·8 | 11·9 | ... | 28·8 | 13·5 | 13·3 |
| | 2.30 | 15·5 | ... | 21 9 | 14·7 | ... | 31·2 | 25·5 | 14·6 |
| 16/6 | 10.45 | 12·9 | ... | 28·9 | 13·3 | ... | 30·6 | 29·8 | 32·4 |
| | 2.30 | 14·3 | ... | 33·1 | 14·3 | ... | 31·5 | 31·6 | 32·1 |
| 17/6 | 10 30 | 12·9 | ... | 20·9 | 13·2 | ... | 29·7 | 14·4 | 20·6 |
| | 2.15 | 13·6 | .. | 19·7 | 13 5 | ... | 32·0 | 14·0 | 18·1 |
| 18/6 | 10·45 | 13·7 | ... | 14·9 | 13·4 | ... | 28·9 | 14·3 | 13·9 |
| | 2.15 | 14·8 | ... | 15·2 | 18·2 | ... | 31·6 | 25·1 | 14·8 |
| 19/6 | 10.45 | 13·7 | ... | 24·1 | 20·2 | ... | 30·6 | 28·8 | 13·8 |
| | — | — | ... | — | — | ... | — | — | — |
| 22/6 | 10.30 | 12·5 | ... | 18·1 | 13·3 | ... | 30·2 | 28 1 | 12·4 |
| | 2 0 | 13·8 | ... | 29·5 | 15·3 | ... | 32·6 | 32 0 | 13·7 |
| 23/6 | 10.15 | 10·9 | .. | 24·3 | 18·0 | ... | 30·3 | 28·7 | 31·9 |
| | 2.30 | 15 3 | ... | 32·2 | 16·4 | ... | 32·9 | 32·3 | 32·7 |
| 24/6 | 10.30 | 12·1 | ... | 27·4 | 17·5 | ... | 20·6 | 25·0 | 18·4 |
| | 2.30 | 15·9 | ... | 33·0 | 16·6 | ... | 32·8 | 31 5 | 15·9 |
| 25/6 | 10.45 | 13 6 | ... | 28·8 | 14·6 | ... | 29·6 | 27·7 | 13·5 |
| | 2.30 | 15·5 | .. | 32·9 | 14·9 | ... | 32·5 | 31 7 | 14·6 |
| 26/6 | 10.45 | 15·5 | .. | 30·8 | 15·1 | ... | 30·2 | 28·4 | 14·3 |
| | 2.30 | 16·2 | ... | 30·5 | 15·7 | ... | 32·6 | 30·1 | 15·2 |

TABLE I.—*Continued.*

| Date. | Time. | Air-temp. | Temperature of Echidna No. 1. | No. 2. | No. 3. | No. 4. | No. 5. | No. 6. | No. 7. |
|---|---|---|---|---|---|---|---|---|---|
| 30/6 | 10.15 | 16·5 | ... | 25·3 | dead | ... | 31·6 | 28·5 | 14·9 |
| | 2.30 | 16·0 | ... | 28·8 | ... | ... | 29·3 | 31·3 | 19·0 |
| 1/7 | 10.45 | 14·2 | ... | 19·8 | ... | ... | 28 3 | 21·1 | 29 5 |
| | — | — | ... | — | . | ... | — | — | — |
| 2/7 | 10 45 | 14·8 | | 18·9 | ... | ... | 29·6 | 14·8 | 23·8 |
| | 2.15 | 14·5 | ... | 19·9 | ... | ... | 33·0 | 15·9 | 21·2 |
| 3/7 | 10.30 | 15·5 | ... | 20·0 | ... | . | 30·3 | 31·6 | 18 9 |
| | 2 30 | 16·4 | ... | 21·4 | | | 33·0 | 32·7 | 17·9 |
| 6/7 | 10.30 | 14·8 | ... | 24·7 | ... | ... | 30·0 | 29·2 | 13·6 |
| | 2.0 | 15 9 | ... | 25·0 | ... | | 32·6 | 32·1 | 14 7 |
| 7/7 | 10.15 | 13·8 | . | 18·1 | ... | . | 29·7 | 28·5 | 13·9 |
| | 2.15 | 15 8 | ... | 17·1 | ... | . | 31·7 | 31·3 | 14·3 |
| 8/7 | 10.30 | 10 6 | ... | 10·9 | ... | ... | 30·0 | 13 3 | 11 8 |
| | 2.15 | 12·4 | . | 11·5 | . | | 32·9 | 18·5 | 11·6 |
| 9/7 | 10.30 | 12·1 | ... | 11·4 | ... | .. | 28 6 | 16·3 | 11·1 |
| | 2.0 | 14·0 | ... | 13·3 | | ... | 32·3 | 31·3 | 12·4 |
| 10/7 | 10.30 | 10·6 | . | 10·4 | ... | | 28·2 | 24·7 | 10·1 |
| | 2.30 | 12·5 | ... | 11·3 | ... | | 31·9 | 29·0 | 10·9 |
| 13/7 | 10.30 | 9·9 | ... | dead | ... | ... | 29 3 | 10·7 | 32 0 |
| | 2.45 | 12 2 | ... | ... | ... | | 32·4 | 11·2 | 32·4 |
| 14/7 | 10.15 | 10·6 | ... | ... | ... | ... | 28·4 | 9·9 | 18·8 |
| | 2.15 | 13·0 | ... | ... | ... | ... | 29·4 | 11·3 | 15·5 |
| 15/7 | 10.45 | 12 0 | ... | ... | ... | ... | 25 1 | 9·9 | 10·2 |
| | — | 13·1 | .. | ... | | . | 27·0 | 11·5 | 12·0 |
| 16/7 | 10.0 | 8·4 | ... | ... | ... | .. | 29 5 | 28·3 | 8·9 |
| | 2.0 | 11·3 | ... | . | ... | . | 32·3 | 31·3 | 9·9 |
| 17/7 | 10 15 | 10·1 | ... | ... | | | 27 8 | 25·8 | 15·0 |
| | 2.15 | 11·9 | ... | .. | ... | ... | 30·1 | 29·8 | 13·3 |
| 20/7 | 11 0 | 11·6 | ... | ... | ... | . | 30·6 | 12·1 | 12·1 |
| | 2.30 | 13·1 | ... | ... | | ... | 32·4 | 12·3 | 12·6 |
| 21/7 | 10.45 | 12·0 | ... | ... | ... | | 19 2 | 12·7 | 11·3 |
| | 2.30 | 13·4 | ... | ... | ... | | 29·4 | 13·3 | 12·1 |
| 22/7 | 10.30 | 12·1 | .. | ... | | ... | 30·3 | 11·7 | 12·1 |
| | 2.30 | 13·6 | .. | ... | ... | .. | 31·7 | 13·7 | 24·8 |
| 23/7 | 10.30 | 9·8 | . . | ... | .. | ... | 29 4 | 30·6 | 31·4 |
| | 2.30 | 13·7 | ... | ... | ... | .. | 32·5 | 31·7 | 32·6 |
| 24/7 | 11.0 | 12·1 | ... | ... | ... | ... | 30·7 | 27·3 | 30·6 |
| | 2.0 | 13·9 | . | ... | . | . | 32·7 | 31·9 | 32 5 |
| 27/7 | 10.15 | 11·1 | ... | ... | . | ... | 21·5 | 26·2 | 11·2 |
| | 2.45 | 13·8 | ... | ... | ... | ... | 31·3 | 30·1 | 13 6 |
| 28/7 | 10.15 | 10·6 | . | ... | ... | ... | 28·4 | 20·8 | 10·8 |
| | 2.15 | 14·8 | ... | ... | ... | .. | 30·8 | 30·0 | 12·6 |
| 29/7 | 10.30 | 13·1 | ... | .. | ... | ... | 29·2 | 29·6 | 12·1 |
| | 2 30 | 15·5 | .. | ... | ... | ... | 32·6 | 31·8 | 13·3 |
| 30/7 | 10.30 | 12·4 | ... | ... | .. | ... | 26·4 | 26 8 | 11·5 |
| | 2.30 | 15·9 | ... | ... | .. | . | 31·3 | 32·2 | 13 8 |
| 31/7 | 10.15 | 12·7 | .. | ... | ... | ... | 29·1 | 25·8 | 12 4 |
| | 2.15 | 15·1 | | ... | . | . | 31·1 | 30·2 | 13·8 |
| 4/8 | 10.15 | 13·3 | ... | ... | ... | ... | 30·6 | 22·7 | ... |
| | 2.15 | 17·0 | ... | .. | .. | ... | 31·8 | 30·5 | ... |

TABLE i.—*Continued.*

| Date. | Time. | Air-temp. | Temperature of Echidna. No.1. | No.2. | No.3. | No.4. | No.4. | No.6. | No.7. |
|---|---|---|---|---|---|---|---|---|---|
| 5/8 | 10.30 | 12·9 | . | ... | ... | ... | 28·4 | 28·8 | ... |
| | 2.15 | 17·1 | ... | ... | . | ... | 27·4 | 31·9 | ... |
| 6/8 | 10.30 | 14·9 | ... | ... | ... | ... | 23·7 | 29·3 | ... |
| | 2.45 | 16·1 | ... | ... | .. | .. | 23·9 | 29·1 | |
| 7/8 | 10.45 | 14·2 | ... | ... | . | ... | 14·4 | 27·9 | ... |
| | 2.15 | 17·3 | ... | .. | ... | ... | 16·1 | 31·8 | |
| 10/8 | 10.30 | 12·9 | ... | ... | | ... | dead | 23·9 | ... |
| | 2.15 | 15·7 | ... | ... | | ... | | 31·3 | ... |
| 11/8 | 10.15 | 11·8 | ... | .. | ... | . | .. | 26·9 | .. |
| | 2.15 | 16·4 | ... | . | | ... | ... | 30·7 | ... |
| 12/8 | 10.45 | 14·1 | .. | ... | . | ... | .. | 27·4 | ... |
| | — | — | ... | ... | . | ... | ... | — | ... |
| 13/8 | 10.45 | 13·3 | ... | ... | .. | ... | . | 29·8 | .. |

In the case of Echidna No.1, it will be seen that, between April 30th, and May 22nd, its morning-temperature varied between 30·8° and 25·1°, except on May 19th, and 20th, when very low body-temperatures were recorded; its afternoon-temperatures varied between 32·5° and 27·6°C. On May 25th, the first definite hibernation was noticed, the temperature of the animal being very close to that of the air. Observation of the animal's temperature was at once suspended in order not to disturb the hibernation, but a partial awakening occurred on June 1st. The animal was again torpid next day, and died three days later.

In the case of Echidna No.2, between April 30th and June 12th, with the exception of June 4th, 5th, and 9th, when low body-temperatures were observed, the morning-temperatures of the animal varied between 32·1° and 25·1°C., the afternoon-temperatures between 33·4° and 30·8°C. The hibernation of this animal was very erratic; the first definite signs of it were observed on June 15th. The animal was torpid on June 15th, June 18th, and from June 30th to July 2nd. The temperature rose somewhat on July 7th, but fell again next day, and remained almost at the level of the temperature of the air till the death of the animal on July 10th.

Between April 30th and June 22nd, Echidna No. 3 showed no signs of hibernation. During this period its morning-tem-

perature varied between 31·8° and 26·1°C., its afternoon-temperature between 31·8° and 34·0°C. On June 22nd, the animal commenced to hibernate, and was left undisturbed. On June 26th, the animal began to wake up, however, but became torpid again on the 28th. It was again left undisturbed, but woke again on July 5th. From July 9th, till the time of its death on July 29th, the animal hibernated continuously. This is the longest period of continuous hibernation shown by any of the Echidnas under my observation.

The temperature of Echidna No.4 behaved, on the whole, in rather an erratic fashion. From April 30th, to May 15th, its morning-temperature varied between 29·1° to 23 2°C., its afternoon-temperatures between 33·7° and 28·2°C. From May 16th, to May 21st, the temperature of the animal approached towards that of the air, the animal meanwhile becoming more and more sluggish, and finally quite torpid. Next day, the temperature of the animal rose suddenly to 28·8°C., but immediately began to fall again almost as rapidly, reaching the level of the temperature of the air on May 25th. The animal became torpid again and remained in this condition until its death on June 1st. As this animal was in a poor state of health when it came under observation, its temperatures are not regarded as normal.

Echidna No.5 is peculiar, as it showed only one short period of hibernation during the Winter, from June 2nd, to June 4th. For the remainder of this period, with the exception of the mornings of May 27th, and 29th, June 9th, July 19th, and 27th, and the three days preceding its death, the morning-temperature of the animal varied between 31·6° and 25·3°C., the afternoon-temperatures between 34·2° and 26·5°C, although only on one or two occasions were the lower values reached.

The morning-temperatures of Echidna No.6 remained between 30·9° and 27·1°C, the afternoon-temperatures between 33·5° and 30·4°C., from April 30th, to May 26th. On June 16th, the first definite signs of hibernation were observed. This animal hibernated for a day or two on five separate occasions during the Winter. These occasions were June 17th, July 2nd, 9th, and 10th, July 14th, 15th, and 16th, July 20th, 21st, and 22nd. It

will be noticed that, between the periods of hibernation, the temperature of the animal rose very sharply to its normal values in the vicinity of 30°C. This animal was injured on one occasion (May 27th) while inserting the thermometer, and was left undisturbed for a few days to recover. It was still alive and in good health at the end of the period of the observations.

Echidna No.7 showed the first signs of hibernation on May 20th. Before that date, its morning-temperature varied between 30·2° and 26·1°C., its afternoon-temperature between 33·3° and 29·2°C. The first period of hibernation began on May 25th; the animal was left undisturbed, but became active again on June 1st. This animal hibernated on eight successive occasions during the Winter, most of its time during that season being spent in the torpid condition. The periods of hibernation were May 25th 29th, June 4th, June 9th-11th, June 15th, June 17th-22nd, June 23rd-30th, July 3rd-10th, July 14th-21st, and, finally, from July 27th till the death of the animal on August 1st.

TABLE ii.

*Spring and summer temperatures of Echidna.*

| Date. | Time. | Air-temp. | Echidna 6. | | Echidna 8 | | Echidna 9. | | Echidna 10. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | temp. | wt. | temp. | wt. | temp. | wt. | temp. | wt. |
| 22/9 | 10.30 | 18·1 | 28·5 | | 30·3 | | ... | | .. | |
| | 2.0 | 21·7 | 32·7 | 1590 | 33·1 | 1175 | | ... | ... | ... |
| 23/9 | 10.0 | 18·0 | 29·5 | | 30·4 | | ... | | ... | |
| | 2.30 | 26·6 | 33·8 | 1570 | 33·6 | 1150 | ... | ... | ... | .. |
| 24/9 | 10.15 | 17·4 | 27·8 | | 29·9 | | ... | | ... | |
| | 2 30 | 23·5 | 33·3 | 1560 | 33·7 | 1120 | ... | ... | ... | ... |
| 25/9 | 10.0 | 14·1 | 25 8 | | 28·8 | | | | ... | |
| | 2.15 | 19·9 | 32·2 | 1600 | 33·0 | 1090 | ... | .. | ... | .. |
| 26/9 | 10.0 | 13·8 | 27·9 | | 25·9 | | ... | | ... | |
| | — | — | — | | — | | ... | | .. | |
| 28/9 | 10.10 | 16·9 | 27·5 | | 24·6 | | ... | | ... | |
| | 2.30 | 22·2 | 32 4 | 1550 | 32·0 | 1030 | ... | ... | ... | ... |
| 29/9 | 10.30 | 15·7 | 28·4 | | 31·0 | | ... | | ... | |
| | 2.15 | 21·4 | 32·8 | 1570 | 33·6 | 990 | .. | .. | ... | ... |
| 30/9 | 9.45 | 17·3 | 31·2 | | 30·6 | | ... | | ... | |
| | 2.15 | 22·0 | 32·9 | 1500 | 32·4 | 960 | . | ... | ... | ... |
| 1/10 | 10.30 | 18·1 | 29 8 | | dead | | ... | | ... | |
| | 2.40 | 23·2 | 32·4 | 1780 | ... | .. | ... | ... | .. | ... |
| 2/10 | 10.30 | 15·4 | 28·0 | | ... | | 29·9 | | ... | |
| | 2.45 | 16 1 | 30·8 | 1760 | ... | .. | 30·8 | 1890 | ... | ... |
| 6/10 | 10.20 | 18·2 | 30·4 | | .. | | 29·0 | | ... | |
| | 2.30 | 25·4 | 33·5 | 1590 | ... | ... | 30·0 | 1970 | ... | .. |

TABLE ii.—*Continued.*

| Date. | Time. | Air-temp. | Echidna 6. | | Echidna 8. | | Echidna 9. | | Echidna 10. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | temp. | wt | temp. | wt. | temp. | wt. | temp. | wt. |
| 7/10 | 10.15 | 18·9 | 30·2 | | ... | | 30·0 | | ... | |
| | 2.30 | 25·3 | 33·2 | 1540 | .. | ... | 31·3 | 1980 | ... | ... |
| 8/10 | 10.30 | 20·3 | 30·3 | | .. | | 30·8 | | .. | |
| | 2.30 | 21·2 | 32·6 | 1590 | ... | ... | 30·4 | 1930 | ... | ... |
| 9/10 | 10.30 | 23·4 | 29·5 | | .. | | 30·2 | | ... | |
| | 2.30 | 29·6 | 33·5 | — | . | ... | 31·5 | — | ... | ... |
| 12/10 | ... | . | ... | | ... | | ... | | ... | |
| | 2.55 | 21·6 | 33·2 | 1640 | .. | ... | 29·9 | 1850 | ... | ... |
| 13/10 | 10.25 | 18·8 | 29·6 | | ... | | 30·3 | | ... | |
| | 2.20 | 24·2 | 33·5 | 1650 | ... | ... | 31·4 | 1800 | . | ... |
| 14/10 | 10.30 | 22·6 | 31·1 | 1750 | ... | ... | 30·4 | ... | ... | . |
| | 2.25 | 22·3 | 33·1 | | ... | | 29·7 | | ... | |
| 15/10 | 10.20 | 17·0 | 29·6 | | ... | | 30·0 | | ... | |
| | 2.30 | 17·2 | 32·1 | 1740 | ... | ... | 32·0 | 1760 | ... | ... |
| 16/10 | .. | .. | ... | | ... | | ... | | ... | |
| | 2.35 | 17·1 | 32·0 | 1800 | ... | ... | 30·4 | 1660 | ... | ... |
| 19/10 | 10.30 | 15·9 | 24·9 | | ... | | 16·5 | | ... | |
| | 2.15 | 18·3 | 31·7 | 1650 | ... | ... | 17·2 | 1590 | ... | ... |
| 20/10 | 10.15 | 16·2 | 27·8 | | ... | | dead | | ... | |
| | 2.30 | 17·6 | 32·2 | 1680 | ... | ... | ... | ... | 32·4 | 1680 |
| 21/10 | 10.25 | 18 2 | 29·4 | | ... | | ... | | 29·9 | |
| | 2.10 | 22·5 | 33·2 | 1730 | ... | ... | ... | ... | 32·2 | 1640 |
| 22/10 | 10.30 | 19·6 | 29·4 | | ... | | ... | | 29·0 | |
| | 2·15 | 36 8 | 32 5 | 1900 | . | ... | .. | ... | 31·4 | 1610 |
| 23/10 | 10.0 | 19·9 | 28·3 | | ... | | ... | | 26·7 | |
| | 2.10 | 26 8 | 33·2 | 1860 | ... | .. | ... | ... | 33·2 | 1570 |
| 26/10 | 10.30 | 28·9 | 31·9 | | ... | | ... | | 29·8 | |
| | 2.20 | 30 4 | 34·0 | 1690 | ... | . | .. | ... | 32·0 | 1560 |
| 27/10 | 10.15 | 22·8 | 29·8 | | ... | | ... | | 28·3 | |
| | 2.20 | 27·9 | 33·5 | 1760 | ... | .. | ... | ... | 33·5 | 1630 |
| 28/10 | 10.30 | 19·3 | 29·2 | | ... | | .. | | 28·4 | |
| | 2.30 | 20·2 | 32·3 | 1740 | ... | ... | ... | .. | 32·1 | 1570 |
| 29/10 | 10.30 | 21·2 | — | | ... | | ... | | 30·3 | |
| | 2.15 | 24·9 | 33·3 | 1800 | ... | ... | ... | ... | 33·1 | 1590 |
| 30/10 | 10.25 | 27·4 | 30·9 | | ... | | ... | | 31·5 | |
| | 1.45 | 34·2 | 33·9 | 1820 | ... | ... | ... | ... | 33·0 | 1620 |
| 2/11 | 10.20 | 20 5 | 31·1 | | ... | | .... | | 25·6 | |
| | 2.15 | 21·9 | 32·7 | 1740 | .. | ... | ... | ... | 31·2 | 1530 |
| 3/11 | 10.30 | 22·3 | 30·9 | | ... | | .. | | 24·4 | |
| | 2.25 | 23·7 | 33·1 | 1870 | ... | ... | ... | ... | 32·2 | 1560 |
| 4/11 | 10.10 | 20·9 | 29·8 | | ... | | ... | | 29·3 | |
| | 2 25 | 25 6 | 33·4 | 1840 | ... | ... | .. | ... | 32·2 | 1550 |
| 5/11 | 10.15 | 23·8 | 30·7 | | ... | | ... | | 29·6 | |
| | 2.10 | 28·4 | 34·0 | 1860 | ... | .. | ... | ... | 31·9 | 1530 |
| 6/11 | 10.20 | 22·9 | 30·2 | | ... | | ... | | 29·4 | |
| | 2.40 | 24·4 | 33·7 | 1820 | ... | ... | ... | ... | 33·0 | 1490 |
| 9/11 | 10.35 | 25·0 | 32·4 | | .. | | .. | | 31·6 | |
| | 2.30 | 22·2 | 33·3 | 1760 | ... | ... | ... | ... | 32·2 | 1420 |

TABLE II. —*Continued.*

| Date. | Time | Air-temp. | Echidna 6. | | Echidna 8. | | Echidna 9. | | Echidna 10. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | temp. | wt. | temp. | wt. | temp. | wt. | temp. | wt. |
| 10/11 | 10.25 | 25·0 | 31·4 | | ... | | ... | | 30·0 | |
| | 3.0 | 29·2 | 33·9 | 1900 | .. | . | .. | ... | 32·7 | 1440 |
| 11/11 | 11.10 | 19·6 | 30·7 | | ... | | ... | | 27·4 | |
| | 2.30 | 20·8 | 32·4 | 1950 | ... | .. | ... | .. | 30·6 | 1420 |
| 12/11 | 10.20 | 21·6 | 28·3 | | ... | | ... | | 29·3 | |
| | 2.20 | 22·7 | 32·4 | 1860 | ... | .. | ... | ... | 31·2 | 1360 |
| 13/11 | 10.0 | 22·8 | 31·7 | | ... | | ... | | 27·8 | |
| | 2.30 | 28·3 | 33·7 | 1850 | ... | ... | ... | ... | 32·2 | 1330 |
| 16/11 | 10.15 | 25·1 | 32·5 | | ... | | ... | | 30·4 | |
| | 2.35 | 28·9 | 33 8 | 1810 | .. | ... | . | ... | 31·7 | 1290 |
| 17/11 | 9.50 | 25·5 | 32·1 | | ... | | ... | | 32·2 | |
| | 2.20 | 24·2 | 32·6 | 1950 | | ... | ... | . | 31·9 | 1270 |
| 18/11 | 10.5 | 22·2 | 30·6 | | | | ... | | 30·3 | |
| | 2.40 | 23·1 | 31·8 | 2000 | .. | ... | ... | .. | 30·9 | 1210 |
| 19/11 | 10.5 | 21·4 | ... | | ... | | .. | | 27·0 | |
| | 2.15 | 24·3 | 31·4 | 1910 | ... | .. | ... | .. | 28·6 | 1150 |
| 20/11 | 10.20 | 25·8 | 31·1 | | .. | | ... | | dead | |
| | 2.25 | 27·4 | 34·0 | 1920 | ... | . | ... | .. | ... | ... |
| 23/11 | 10.0 | 22·9 | 33·2 | | .. | | ... | | ... | |
| | 2.30 | 24·2 | 33·8 | 1760 | . | ... | ... | ... | ... | ... |
| 24/11 | 10.5 | 24·2 | 31·8 | | ... | | ... | | ... | |
| | 2 25 | 28·3 | 33·7 | — | .. | ... | ... | ... | ... | ... |
| 25/11 | 9.55 | 24·3 | 31·1 | | . | | | | .. | |
| | — | — | — | 1820 | .. | ... | ... | | ... | ... |
| 27/11 | 10.20 | 20·5 | 28·9 | | .. | | ... | | .. | |
| | 3.15 | 22·6 | 33·0 | 19'0 | ... | ... | ... | ... | ... | ... |
| 30/11 | — | — | — | | .. | | ... | | ... | |
| | 2.0 | 21·6 | 33·0 | 1750 | . | ... | ... | ... | ... | ... |
| 1/12 | 10.10 | 20·8 | 30·1 | | . | | .. | | .. | |
| | 2.35 | 27·0 | 33·7 | 1820 | .. | ... | ... | ... | .. | ... |
| 2/12 | 10.0 | 22·3 | 28·7 | | . | | .. | | ... | |
| | 2 35 | 26·5 | 33·5 | 1790 | ... | ... | .. | ... | ... | ... |
| 3/12 | 10.15 | 21·8 | 30·0 | | .. | | ... | | .. | |
| | 2.35 | 22·6 | 33·0 | 1820 | ... | ... | ... | ... | ... | ... |
| 4/12 | 10.35 | 21·2 | 29·4 | | ... | | ... | | .. | |
| | 2.15 | 28·3 | 33 5 | 1830 | ... | ... | ... | ... | ... | ... |
| 7/12 | 11.0 | 20·5 | 31·0 | | .. | | ... | | ... | |
| | 2.25 | 21·6 | 32·6 | 1730 | ... | ... | ... | ... | .. | ... |
| 8/12 | 10.40 | 19·7 | 28·7 | | ... | | ... | | | |
| | 2.35 | 23·9 | 31·9 | 1790 | ... | ... | . | ... | ... | ... |
| 9/12 | 10.10 | 22·3 | 30 6 | | ... | | . | | .. | |
| | 2.20 | 28·5 | 33·5 | 1770 | ... | ... | ... | ... | .. | .. |
| 10/12 | 10.35 | 22·9 | 30·5 | | ... | | .. | | ... | |
| | 2.30 | 24·9 | 33·9 | 1840 | ... | .. | ... | ... | ... | ... |
| 11/12 | 10.30 | 24·2 | 31·5 | | ... | | ... | | ... | |
| | 2.25 | 29·6 | 33·4 | 1850 | .. | ... | ... | ... | ... | ... |
| 14/12 | 9.45 | 23·4 | 31·1 | | ... | | ... | | .. | |
| | 3.30 | 25·4 | 33·7 | — | ... | ... | ... | .. | ... | ... |

TABLE ii.—*Continued.*

| te. | Time. | Air-temp. | Echidna 6. | | Echidna 8. | | Echidna 9. | | Echidna 10. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | temp. | wt. | temp. | wt. | temp | wt. | temp. | wt. |
| 12 | 10 40 | 27·3 | 32·7 | | .. | | ... | | ... | |
| | 2.35 | 34·1 | 33·9 | 2100 | ... | ... | | ... | .. | ... |
| 16/12 | 9.40 | 25·3 | 29·4 | | ... | | .. | | ... | |
| | 2.30 | 32·5 | 32·4 | 2010 | .. | ... | ... | ... | ... | .. |
| 12 | 10.10 | 24·8 | 31·9 | | ... | | ... | | ... | |
| | 2.30 | 30 2 | 33·1 | 1920 | ... | ... | ... | ... | ... | ... |
| 12 | 9.55 | 22·2 | 30·6 | | ... | | ... | | ... | |
| | 2.30 | 23·0 | 33·3 | 1900 | | ... | ... | ... | ... | ... |
| 12 | 9.50 | 20·8 | 29·1 | | ... | | .. | | ... | |
| | 3.0 | 20·6 | 31·7 | ... | ... | ... | ... | ... | .. | ... |

In Table ii., a record of the weight of the animals has been added, so that some idea may be gathered of the general state of their health during this period of observation.

The morning-temperatures of Echidna No.6 will be seen, from the above Table, to have varied between 33·2° and 25·8°C., the afternoon-temperatures between 34·0° and 30·8°C. The weight of the animal also showed very large fluctuations, its lowest value being 1540 gms., its highest 2100 gms. The weight, on the whole, increased, however, and the animal was still living and in good health at the end of the period of observation.

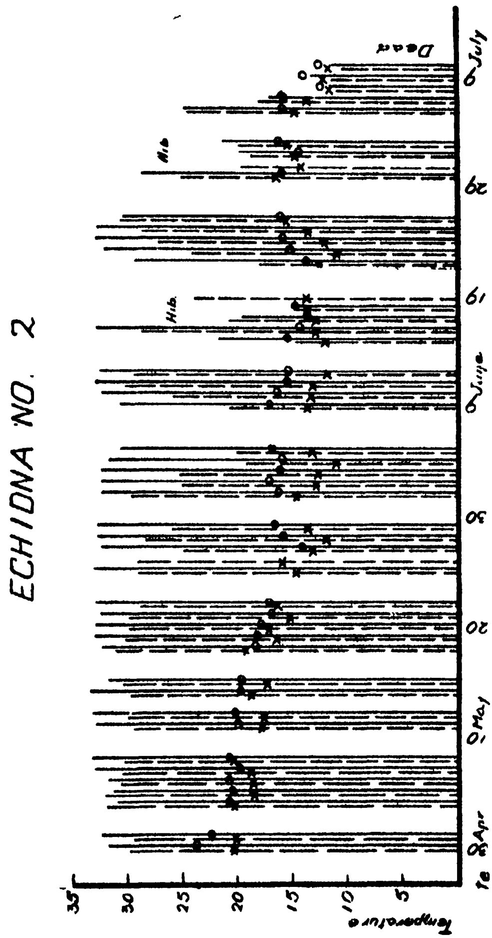
Echidna No.8 lived only a short time while under observation. During this time, its weight steadily fell. Its morning-temperatures varied between 31·0° and 24·6°C., its afternoon-temperatures between 33·8 and 32·0°C.

Echidna No.9 also did not live long, and its weight, too, steadily fell. Its morning-temperatures varied between 30·8° and 29·0°C., its afternoon-temperatures between 31·5° and 29·7°C., except on the last day, when the animal was dying, and its temperature was almost at the level of that of the air.

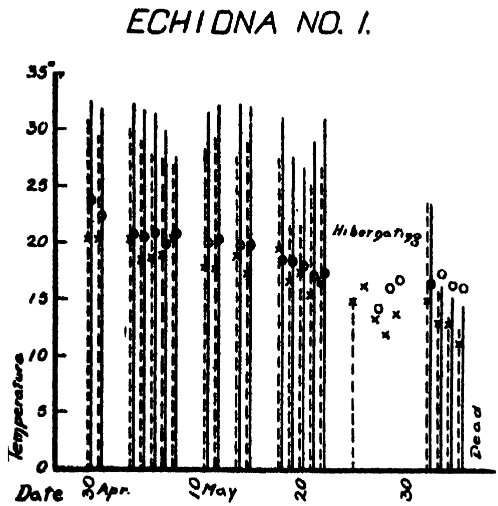
Echidna No.10 also decreased in weight during the period of observation, although it lived about thrice as long as Nos.8 and 9. Its morning-temperatures varied between 32·2° and 24·4°C., its afternoon-temperatures between 33·5° and 30·6°C.

The observations recorded in the above Tables, with the exception of those made on Echidna No.4, have been plotted out graphically in order to render their meaning more evident. In

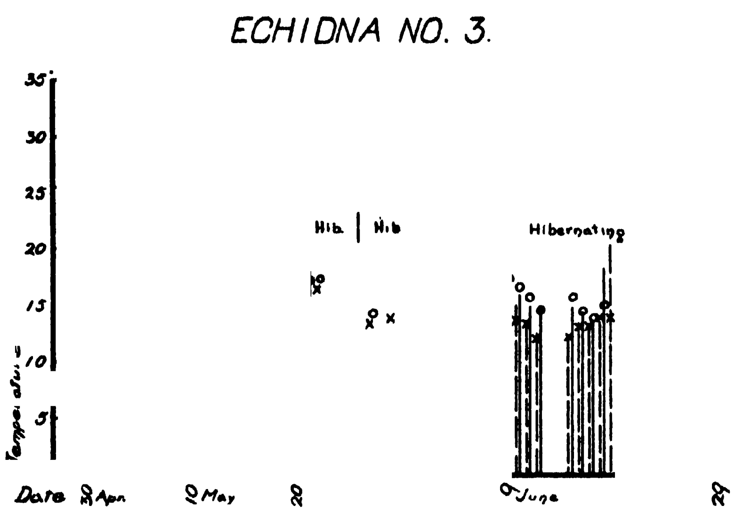
the accompanying diagrams (Text-figs.1-8), the temperatures are represented by vertical lines, the heights of which are proportional to the values of the corresponding temperatures. Morning-temperatures are represented by discontinuous lines, afternoon-temperatures by full lines. The points corresponding to the levels of the temperatures of the air are marked on the ordinates for the temperatures of the animals by crosses in the case of morning-temperatures, and by circles in the case of afternoon-temperatures.



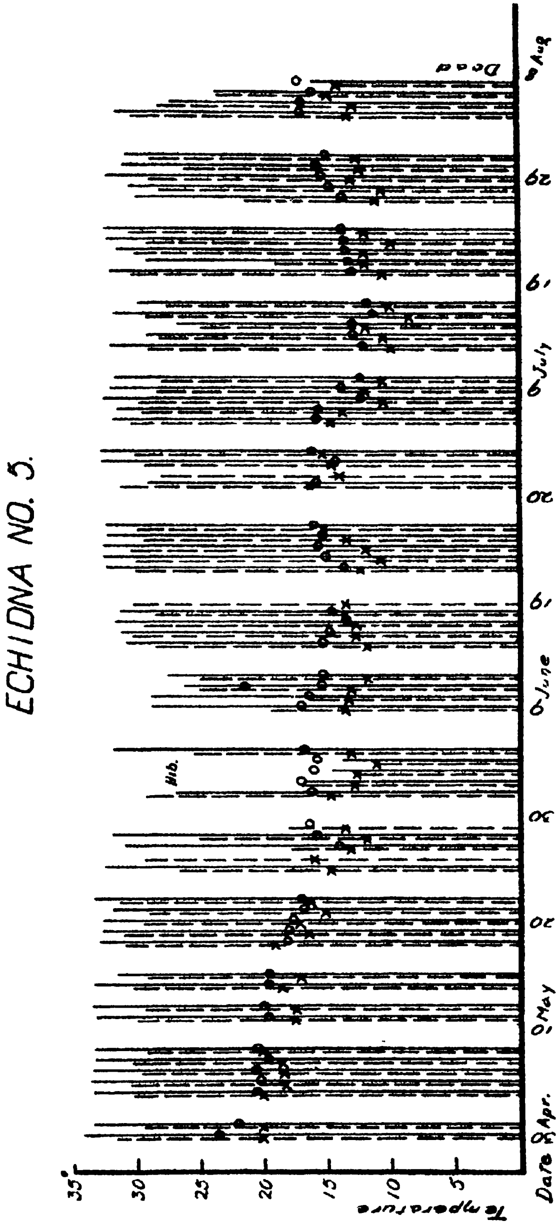

Text-fig.2.—Autumn and Winter temperatures.



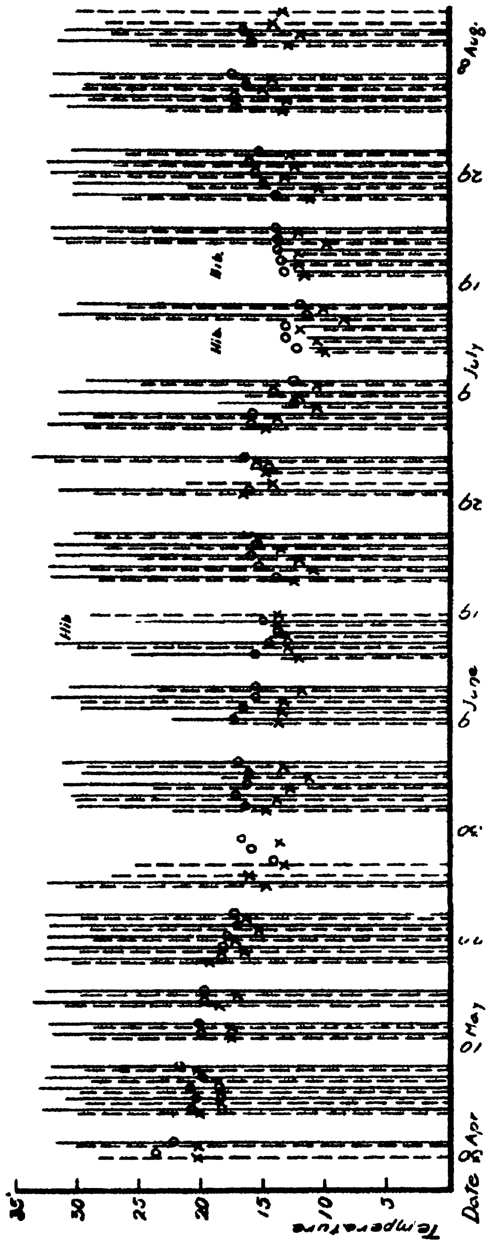

Text.fig.1.—Autumn and Winter temperatures.



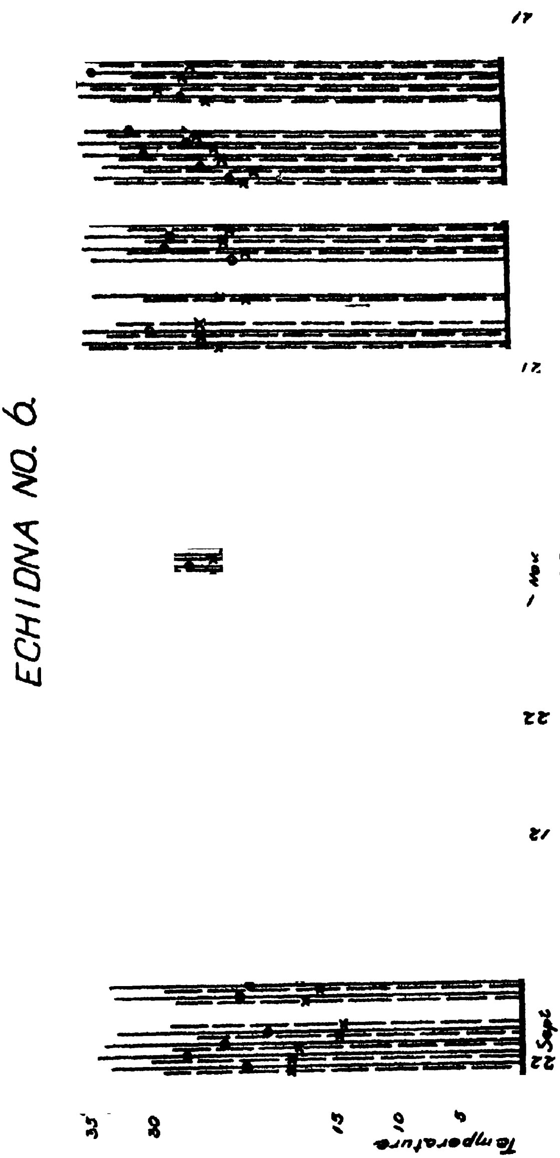

Text-fig.3.—Autumn and Winter temperatures.



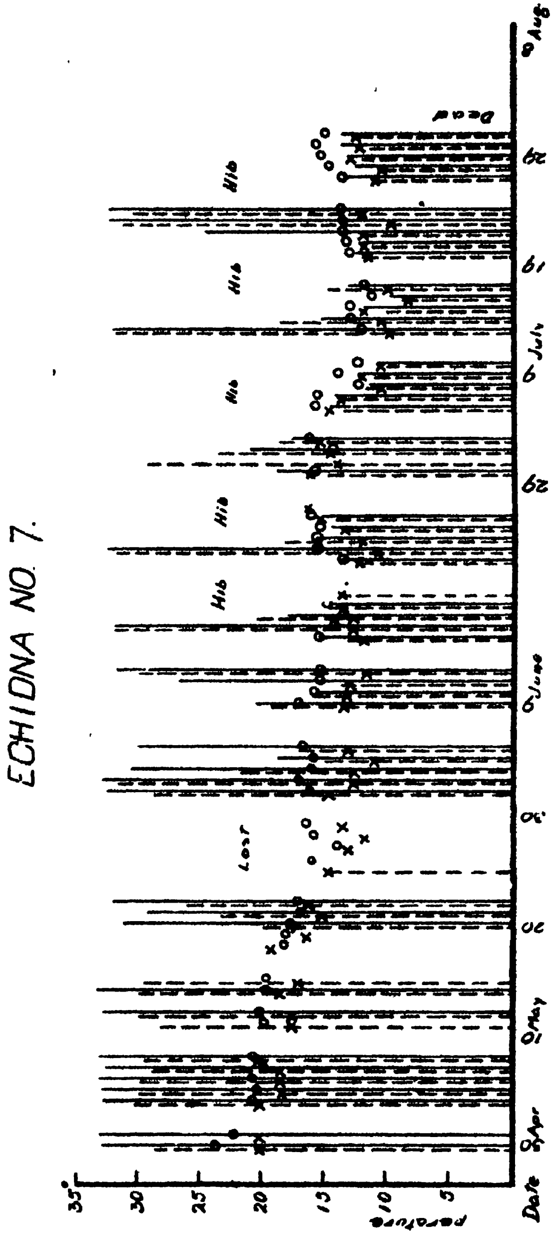

Text-fig. 4.—Autumn and Winter temperatures.



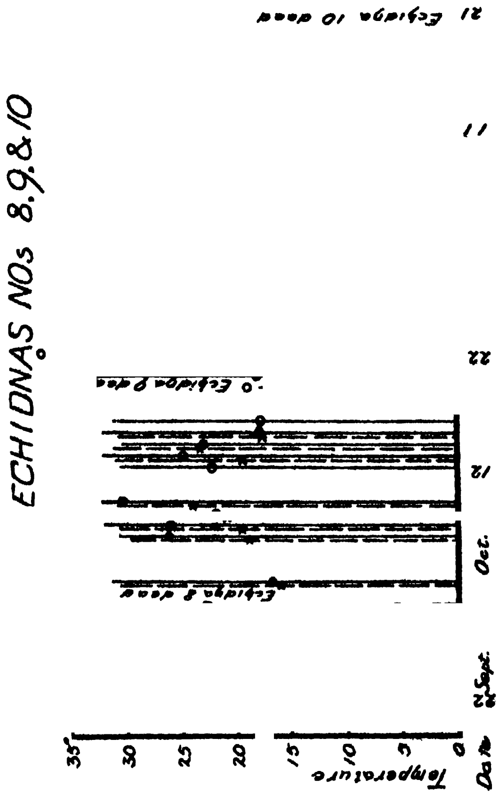

Text-fig. 5.—Autumn and Winter temperatures.




Text-fig. 6.—Spri and Sum ures.




Text-fig. 7.—Autumn and Winter temperatures.




Text-fig. 8.—S

The above series of observations was made, as will be seen, during two periods of the year. The first period extended from April 30th to August 13th, 1914, 105 days, and comprised the end of Autumn and the greater part of Winter. The second period extended from September 22nd to December 21st, 1914, 90 days, and comprised the greater part of Spring and the beginning of Summer. For the first series of observations, Echidnas Nos. 1, 2, 3, 4, 5, 6, and 7 were used; for the second series, Nos. 6, 8, 9, and 10.

As the behaviour of the animals, with regard to their temperature, was considerably different in the winter-portion of the first period from that in the autumn-portion of it, and in the second

period, it will be convenient to consider first the observations obtained during the Winter separately.

*Hibernation of Echidna.*—As previously stated, under the conditions under which I observed Echidna, its hibernation was of a very fitful nature. This fact is well exhibited by the sudden falls and rises of temperature shown in the diagrams giving the winter-temperatures. During the periods of hibernation, the temperatures of the animals remained only slightly higher than the external temperature, following the variation of this like the temperature of a cold-blooded animal. The instances in which the temperatures of Echidna are shown to be actually lower than the external temperatures are due to the occurrence of rises of the latter so rapid that the animals have not warmed-up quickly enough to follow them. The diagrams also show how great are the individual differences between the animals as to the extent to which they hibernate during Winter, the only common feature being the fact that none of them ever hibernated continuously for more than a few days at a time. The longest period of hibernation shown extended over about ten days; the average period, however, was only two or three days. During these periods, the animals lay inert while undisturbed, and showed no visible respiratory movements. If moved and placed in an awkward position, they very slowly readjusted themselves.

No doubt the unnatural conditions, under which the animals were living, had much to do with the intermittence of their hibernation. The taking of an animal's temperature, *per rectum*, twice a day, must have a rather disturbing effect, although specimens which were purposely left undisturbed, during periods of hibernation, did not remain torpid any longer than others whose temperatures were regularly taken.

The behaviour, during Winter, of the Echidnas under my observation was markedly different from that of the animals observed by Martin, who states that "during Winter, Echidna abandons all attempts at homœothermism and hibernates for four months." The fact that the Winter of Melbourne (where Martin's observations were made) is rather colder than that of Sydney, the average midwinter temperatures being 9·5° and

12·2°C., respectively (Hunt, *loc. cit.*), may account for the fact in part, but, apparently, not altogether, as an examination of the diagrams and tables will show that the animals were sometimes awake and active at temperatures lower than those at which they were, at other times, torpid. Temperature seems, therefore, not to be the only factor concerned in the bringing on and maintenance of hibernation, as has also been supposed in the case of European hibernants.

With regard to the rate at which the animals enter into or emerge from a state of hibernation, no very detailed information can be gained from the tables and diagrams, as the temperatures were not observed at frequent enough intervals. The large falls of temperature, indicating the entrance of an animal into a state of hibernation, generally occurred between an afternoon-observation of the temperature and the succeeding morning-observation. Falls of temperature of as much as 16°-17° occurred in this period of twenty hours, as in the case of Echidna No.6, on June 16th-17th, and of Echidna No. 7 on June 3rd-4th. Between the morning- and afternoon-observations, a period of about four hours, comparatively sudden rises of temperature occurred as the animals awoke from hibernation. For example, in the case of Echidna No.6, on June 15th, a rise of 12·0° occurred in the above interval of time; and, in the case of Echidna No.7, a rise of 13·8° occurred on June 5th, in the same period.

*Relation between temperature of Echidna and temperature of air.*—Let us consider now the temperature of Echidna during the periods in which no hibernation occurred, Autumn, Spring, and Summer. It will be seen that, during these periods of observation, firstly, the morning-temperature of the animals was, with only one or two exceptions, lower than the afternoon-temperature; and, secondly, that, although the morning- and afternoon-temperatures each showed variations considerably greater than are met with in the case of human beings, yet these variations seem to have occurred about a sort of mean value; and we may therefore speak of these temperatures as having certain average or mean values, always bearing in mind the very doubtful significance of any average or mean figure as

applied to living organisms. In the following Table, the average morning- and afternoon-temperatures for several individual Echidnas, and for the whole number in the Table are given for the autumn-period, *i.e.*, the period before hibernation.

TABLE iii.

*Average Autumn-temperatures of Echidna.*

| Echidna | Temperature Morning | Temperature Afternoon | No. of obs. |
|---|---|---|---|
| 2 | 30·2° | 32·5° | 18 |
| 5 | 30·2° | 33·2° | 16 |
| 6 | 29·4° | 32·1° | 17 |
| 7 | 29·5° | 31·9° | 10 |
| Average | 29·9° | 32·7° | 61 |

It will be seen that the individual averages do not differ much from one another. Single observations, however, may differ as much as 3° from the average values. The average morning- and afternoon-temperatures from 61 observations distributed over four animals are shown to be 29·9° and 32·7°C. respectively. The average temperature of the air for this period was about 18°C.

In Table iv., are given the average morning- and afternoon-temperatures for individual Echidnas, and for the whole number in the Table for the Spring- and Summer- period, *i.e.*, after hibernation.

TABLE iv.

*Average Spring- and Summer-temperatures of Echidna.*

| Echidna | Temperature Morning | Temperature Afternoon | No of obs. |
|---|---|---|---|
| 6 | 30·1° | 32·9° | 60 |
| 8 | 28·9° | 33·1° | 8 |
| 9 | 30·1° | 30·8° | 9 |
| 10 | 29·0° | 31·9° | 23 |
| Average | 29·4° | 32·2° | 100 |

In this table, too, it will be seen that the individual averages do not differ greatly from one another, although the differences shown are greater than in Table iii. The collective average morning- and afternoon-temperatures, obtained from 100 observations distributed over four animals, are, in this case, 29·4° and 32·2°C., respectively, values slightly lower than those given in the preceding Table, although the average temperature of the air for this period was about 23°C., or 5° higher than in the autumn-period. The differences from the average values shown by single observations are rather greater than was the case with the autumn-temperatures, differences of about 5° occurring in a few cases. This may possibly be due, in part, to the fact that the health of the animals examined in Spring and Summer, with the exception of that of No.6, was not so good as that of those examined in Autumn. The former animals lived only 1-3 weeks while under observation, whereas the latter lived considerably longer, on the whole. It is to be noted, however, that the variations in the temperature of Echidna No.6, which has survived all the others, were as great during the spring-period as those of the animals which died.

It has been seen that, outside of the winter-period, the morning-temperature of Echidna was almost invariably lower than the afternoon-temperature; the average difference for the whole of the observations was 2·8°C., but there were considerable variations from this value. It will be seen, too, that, in the great majority of cases, the external temperature was also higher in the morning than in the afternoon. In spite of this general agreement in the direction of the changes of the temperature of the air and that of the changes of the temperature of the animals, the grounds do not seem sufficient for concluding immediately that the variations in the temperature of the animal are due to those of the temperature of the air. In the first place, there were several instances in which the temperatures of the air in the morning were greater than in the afternoon, and yet the temperatures of the animals increased towards the afternoon in the usual way. These instances are collected together in the following Table.

TABLE V.

*Relation of temperature of Echidna to temperature of air.*

| Date. | Temperature of air | | Temperature of air | |
|---|---|---|---|---|
| | Morning | Afternoon | Morning | Afternoon |
| 18/5/14 | 19·3° | 18·3° | 27·4° | 31·0° |
| | | | 31·2° | 32·0° |
| | | | 31·8° | 33·2° |
| | | | 31·0° | 33·1° |
| | | | 30·3° | 32·5° |
| 30/6/14 | 16·5° | 16·0° | 29·3° | 31·3° |
| | | | 31·6° | 29·3° |
| 2/7/14 | 14·8° | 14·5° | 29·6° | 33·0° |
| 14/10/14 | 22·6° | 22·3° | 31·1° | 33·1° |
| | | | 30·4° | 29·4° |
| 9/11/14 | 25·0° | 22·2° | 32·4° | 33·3° |
| | | | 31·6° | 32·2° |

As will be seen from the above Table, there were only two occasions on which a reversal of the direction of change of the temperature of the air was accompanied by a similar reversal in the direction of variation of an animal's temperature, and, on each of these occasions, this reversal was shown only by one of two animals under observation.

In addition to these cases in which the temperature of the air fell, instead of rising, between morning- and afternoon-observations, there were many occasions on which the rise of the temperature of the air was less than that of the temperature of the animals. Further, there were four occasions on which, although the temperature of the air rose between morning and afternoon, that of an animal fell in the same interval of time; and these do not include those cases where erratic behaviour of the temperature of an animal was due either to the onset or to the close of a period of hibernation.

From the above facts, therefore, it seems that the daily variation of the temperature of Echidna does not entirely depend upon that of the temperature of the air, but is, in part, of the same nature as the daily variation observed in the case of other mammals (of man in particular), which is regarded as quite independent of the variations of the temperature of the air, and which, as in the case of Echidna, consists of an increase, though a much smaller one, between morning and afternoon. The mag-

nitude and unevenness of the daily variation in the case of Echidna are quite in keeping with the general behaviour of its temperature. It must be remembered, too, that temperatures were observed only at two times of the day, and these may not have coincided with the extremes of variation of the animals' temperatures.

If one considers now the relation of a series of morning- or of afternoon-temperatures to the corresponding temperatures of the air, it will be found that the variations of the former sometimes take place in the same direction as those of the latter, and at other times in the opposite direction. The prevailing tendency is, however, for the variations of the air-temperatures and of the body-temperatures of the animals to be in the same direction, so that there seems to be some connection between the two. This view is further supported by the comparison of the mean autumn-temperatures of Echidna No.6, with the mean spring- and summer-temperatures of the same animal. The air-temperatures during Autumn were considerably lower than those during Spring and the beginning of Summer. The average temperatures of the animal were: Autumn, morning, 29·4°, afternoon, 32·1°; Spring and Summer, morning, 30·1°, afternoon, 32·9°C. Over these fairly long periods, then, higher temperatures of the animal were, as a rule, associated with higher air-temperatures, although the evidence of any causal connection between the two is not very strong. It will be remembered, however, that the average morning- and afternoon-temperatures of several animals (Tables iii. and iv.) were slightly higher in Autumn than in Spring.

*Summary.*—(1). During the winter-months, the Echidnas under observation hibernated intermittently, their temperatures approximating to those of the air during the periods of hibernation,

(2). Outside of the periods of hibernation, these Echidnas maintained a temperature which was fairly constant (30-33°C.), although lower than that of other mammals. Echidna, therefore, is a true homoiothermal animal.

(3). The temperature of these Echidnas showed a daily variation, which seemed to be, to some extent, independent of the variations of the external temperature.

(4). Apart from the bringing on of hibernation, there is an indication that change of the external temperature has an effect, although not a simple or immediate one, on the body-temperature of Echidna, as the average temperature of an animal in Spring was slightly higher than that of the same animal in Autumn.

In conclusion, I wish to express my indebtedness to Professor Sir Thomas Anderson Stuart, in whose laboratory this work was done, and to Assistant-Professor Chapman, for his helpful advice during the course of the work.

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